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THE INFLUENCE OF AN EXPANSIVE CEMENT ON CRACKING IN A CEMENT TREATED BASE

A THESIS

Presented to

The Faculty of the Graduate Division

by

Robert Roland Vergnolle

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THE INFLUENCE OF AN EXPANSIVE CEMENT ON

CRACKING IN A CEMENT TREATED BASE

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SUMMARY

This investigation was made to determine if there would be a reduction or elimination in the amount of cracking, which frequently occurs when stabilizing soils with Portland cement, by using an expansive cement.

The soil used in this experiment was a well graded micaceous silty sand from the vicinity of Decatur, Georgia. The Portland cement used was commercially available Type I cement, and the expansive cement used was commercially available ChemComp - shrinkage compensated cement.

Several test series were devised, using rectangular 6 in. x 6 in. x 18 in. laboratory test specimens, to show the difference in shrinkage cracking between Portland cement and ChemComp cement stabilized soil. Other factors studied in this investigation were the difference in strength, density, curing conditions and durability, as determined visually, between Type I Portland cement and ChemComp cement. The effect of the condition of restraint while using ChemComp cement to stabilize the soil was also investigated.

The effect of test specimen surface area while using ChemComp cement to stabilize the soil was investigated by using a square 18 in. x 18 in. x 3 in. test specimen. This test series was performed to observe the effect a larger surface area might have on the expansive properties of ChemComp cement and also to compare the cracking which might occur.

In all of the tests, the soil cement mixture was compacted at either 3 per cent below, 3 per cent above or at the soil's optimum moisture content (26, 29 or 32 per cent). The cement percentages used

were 0, 3, 6, 9 and 12 per cent, and the specimens were compacted using the Standard Proctor Compaction effort of 12,750 ft. lbs./cu. ft.

In general, ChemComp cement stabilized soil appears to yield less shrinkage cracking than Portland cement stabilized soil. This was particularly noticeable when the test specimens were compacted at optimum or 3 per cent above the soil's optimum moisture content.

For the soil investigated, restraint apparently has little effect on cracking for the cement contents tested; however, the restrained specimens were in better overall condition than the unrestrained specimens. In the field, the condition of restraint which would occur in a compacted base would probably be somewhere between these laboratory conditions. However, whether the ChemComp specimens were restrained or unrestrained, both appeared in better condition than the Portland cement specimens.

The difference in strength between the two types of cement was only significant for the specimens compacted at a moisture content 3 per cent below the soil's optimum moisture content. This difference showed that the ChemComp cement specimens had approximately 10 to 33 per cent (depending on the cement content) higher strength than the Portland cement specimens.

CHAPTER I

INTRODUCTION

General

In modern pavement construction, the major consideration is the spreading of the load from the surface of the pavement to the subgrade. In recent years, highway wheel loads and traffic volumes have increased; these increases have led to the use of new types of heavy duty pavement sections which in turn has resulted in increased construction costs. Because of this increased cost and the shortage of good materials for constructing bases for high-capacity pavements, there has been a search for new materials and more efficient methods of load spreading (1)[1]. Some of the possible solutions to this problem have been bituminous binders, soil cement, lime-fly ash stabilization, chemical grouting and even the chrome-lignin process (2). Recent research has indicated that bases stabilized with soil cement may spread the load more efficiently than do bases stabilized with other materials (1).

Soil cement is a compacted mixture of pulverized soil, cement and water that, as the cement hydrates, forms a hard and durable paving material (3). As a result, soil cement improves local soils so that they may be used for flexible pavement bases and subbases. Soil cement stabilization permits local meterials to be used to the fullest extent possible,

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1. Numbers given in parenthesis and underlined refer to references listed in the bibliography.

and under certain conditions results in a low first cost (3).

The development of soil cement bases has resulted in some technical problems. One of the problems is the formation of shrinkage cracks during the drying (hardening) process. As soil cement dries, it tends to shrink, thereby developing a pattern of transverse and longitudinal cracks (4,5). These cracks reduce the load spreading ability of the pavement, and allow water to enter into the subgrade causing a weakening of the pavement structure due to an increase in water content (1,12). The factors which govern the shrinkage and subsequent cracking appear to be soil plasticity, the amount of cement used in stabilization, the compaction moisture content, the degree of compaction and the method and time of curing (1). Sowers (1) has pointed out that the greater the degree of compaction and the smaller the moisture and cement contents the less the shrinkage. Therefore, if a low cement content is used and the moisture is kept below the optimum moisture content for the soil, then fewer shrinkage cracks having a smaller size should develop. Furthermore, these smaller cracks can be corrected more easily and economically than the larger cracks resulting from the use of higher cement and water contents. However, the base obtained by using a lower cement content will be weaker.

Shrinkage cracking is also a construction problem in other areas besides soil cement stabilization. In reinforced concrete construction, shrinkage cracking has always caused trouble (6). Recently, the use of expansive cements has been investigated as a possible solution for reducing the shrinkage problem in reinforced concrete members.

Expansive cements are capable of compensating for the shrinkage due to drying that occurs in Portland cement concretes. Actually expansive cements are not new; they have been under investigation for approximately 40 years primarily in France, the USSR and the United States (6,7). The type of expansive cement commercially available in the United States was developed by Alexander Klein (6) of the University of California and is sometimes referred to as Klein cement.[1]

In reinforced concrete, shrinkage is reduced by the expansive cement expanding initially only a slight amount while it is internally restrained by the reinforcing steel. This restraint places a small amount of tension in the steel and a small amount of compression in the concrete which is the opposite of the usual stress condition in a reinforced concrete member. Since the concrete is initially in compression, stresses due to subsequent drying and shrinkage will be essentially relieved (8). An unrestrained ChemComp concrete specimen will show an expansion of approximately the same absolute magnitude as the drying shrinkage expected from Portland cement concrete of the same mix design. This expansion will occur over the first few days of curing, and will be substantially complete in 4 to 6 days (9).

Literature Review

The ability of ChemComp to prevent drying shrinkage cracking is based on the crystal growth of calcium sulfoaluminate (8). At the cement plant, an alteration is made in the fundamental raw mix design; this alteration adds the mineral calcium sulfoaluminate ($C_4A_3SO_3$) to those already

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1. Klein cement is a patented product controlled by the Chemically Prestressed Concrete Corporation of Van Nuys, California, and is sold under the registered trademark of ChemComp - shrinkage compensated cement.

present in Portland cement. This mineral hydrates in the presence of water to form a new mineral known as ettringite. Ettringite, which is one form of calcium sulfoaluminate hydrate, occupies a greater volume than the volumes of water and anhydrous material that go to make it up. Thus its formation causes an increase in absolute volume, and therefore a net expansion (8). The net volume change for ChemComp concrete, after expansion and drying, has been reported to be approximately zero under certain conditions (9). ChemComp cement contains approximately 12 per cent calcium sulfoaluminate and 88 per cent Type II Portland cement (11).

To obtain the benefits of ChemComp, it may be necessary to provide restraint to the specimen so that a compressive force can be induced (9). The reinforcement in reinforced concrete is the internal restraint which is preferable for ChemComp cement to perform properly (9). However, soil cement, which undergoes shrinkage cracking in a similar manner as does reinforced concrete, usually possesses no internal restraint. Recent research (20) has been conducted to investigate the possibility of using bamboo as a type of internal reinforcement for soil cement; Type I Portland cement was used in this investigation. Much of this research dealt with the improvement of the structural properties of a soil cement base. Additional research is necessary in this field using an expansive cement in order to observe whether bamboo reinforcement in a soil cement base will function in a similar manner as steel functions in a reinforced concrete member. Also the economical feasibility of using bamboo reinforcement in soil cement base construction should be investigated.

If internal restraint can not be provided to a soil cement base, then sufficient external restraint may have to be provided if ChemComp can reduce or prevent cracking. Such external restraint could be provided by friction on the bottom and sides of the base course. Some laboratory research (21) has been performed to investigate the amount of frictional restraint produced between concrete pavement slabs and their base course sections. The results of this work indicate that in most cases, depending on the type of base and the existing field conditions, there is some frictional resistance provided between the concrete pavement slab and the base course section. There is probably more friction present between the base and the subgrade since the surfaces of these two sections are rougher and the normal contact stress is larger. However, more research is necessary to determine whether sufficient restraint exists between the base course section and the subgrade in order to produce a compressive stress which is believed to be necessary when using an expansive cement.

Another possible method of external restraint is end anchors constructed at the ends of a pavement section. These end anchors can prevent movement of the ends of the pavement thereby allowing a buildup in compressive stress in the pavement during the curing period (19). At the present time, little research has been performed to show whether expansive cement can aid in preventing cracking in soil cement base stabilization.

The important properties of hydrated soil cement of significance in base course design and construction are strength (usually expressed as the unconfined compressive strength), resiliency, durability, and volume change (1). Tests, experience and theory show that strength, durability and volume change increase with an increase in cement content. However, the higher the cement content, the greater the shrinkage cracking and construction cost. Therefore, the problem arises as to what is the cement content which will best meet all of the above mentioned requirements; obviously there must be a compromise in mix design (1). In the United States, the minimum cement content is often based on durability, as demonstrated by both alternate wetting and drying or alternate freezing and thawing (10). Whichever requires the greater cement content establishes one aspect of the minimum. In some states where there is little chance of severe freezing, the freeze-thaw test is omitted entirely, and the minimum cement content is based on the wet-dry test. A second minimum is sometimes based on strength with the chosen cement content providing at least the following strengths (1):

light to moderate loads	300 psi
very heavy loads	500 psi

Finally, to obtain proper load spreading to soft subgrades, the initial tangent modulus of elasticity of the base should be 20 to 50 times that of the subgrade. With stronger subgrades, lower ratios are acceptable (1). The minimum cement content permissible to meet these requirements of strength and durability are determined by trial (10); when the strength requirements are met, elasticity data collected in previous testing has shown that the elasticity ratio will insure efficient load spreading (1).

As previously mentioned, little research has been performed regarding cracking in cement stabilized soils. Fister (12) performed research to determine how certain factors such as moisture content, cement content, clay content, and temperature differential in the base affected cracking in soil cement base stabilization. The emphasis of this research was placed on cracking which occurred at an early age (during the curing period). Some of the more important results learned from this research were that cement content is not the only factor in producing cracking, and that a temperature differential in the base accelerated the cracking. His results also showed that the type of soil, whether friable or clayey, and the moisture content whether above or below optimum, could be either beneficial or detrimental to the durability and cracking of the soil cement mixtures. Fister also found that certain type soils were more susceptable to cracking than others.

The only organization known to have conducted research on soils stabilized with expansive cements is the Alabama State Highway Department. Hester (13) supervised some laboratory tests on a clay consisting of approximately 40 per cent vermiculite, 20 per cent gibbsite and the remainder halloysite and kaolinite. A mixture consisting of about 70 per cent sand and 30 per cent clay was placed in 6 in. x 6 in. x 36 in. molds. Samples containing 4 per cent Type I Portland cement were compared with other samples of 4 per cent ChemComp cement. The samples were confined within molds until they were fully set. There was a total of 1/4 inch shrinkage using type I Portland cement with no apparent shrinkage using ChemComp cement. No mention was made as to the number of specimens made, the compacting moisture content, or the curing conditions. In conclusion, little work has been done either in the field or laboratory to determine the potential use of expansive cements in soil stabilization.

Scope of Experiment

The purpose of this research was to see if there will be a reduction in the amount of cracking which occurs in cement stabilized soils by the use of an expansive cement. The approach used in this work was to compare the cracking which occurs under several different conditions in a soil cement base using Type I Portland cement with that wich occurs using ChemComp cement. In order to make this study, it was necessary to employ the factors which cause shrinkage cracking: these are soil plasticity, moisture and cement content, curing conditions and the temperature differential which exists in a base. In addition, in soils stabilized with an expansive cement, condition of restraint and surface area appear to have some effect. The relationship of these factors to cracking is as follows:

Soil Plasticity

Plasticity is dependent upon the percentage of clay mineral colloids present in the fine grain fractions of a soil (16). Therefore, the higher the clay content which a soil possesses, the greater the degree of plasticity. These clay mineral colloids are subject to volume changes and have an affinity for water. Because of the clay particles' affinity for water, proper cement hydration in a soil cement mixture may be hindered. This would yield a weaker total structure, and when a volume change occurred, cracking could take place under certain conditions (12).

Cement Content

When the cement content is increased, the total shrinkage of cement-treated mixtures made from soils that exhibit a volume change without cement is decreased. However, the increase in strength associated with the higher cement contents results in wider crack openings. Decreasing the cement content and strength, while yielding greater shrinkage, produces smaller, closely spaced cracks (17,18). Usually it is the wider cracks that are of major concern, and since cracking is related to strength, some control over size and spacing of cracks can be exercised by control of the cement content. However, durability must also be considered (18).

Moisture Content

Clay soils compacted to maximum density at moisture contents greater than optimum tend to exhibit less swell and greater shrinkage. Whereas clay soils compacted to maximum density at moisture contents less than optimum tend to show the opposite effect (12). Therefore, the moisture content that would result in a minimum of cracking for different combinations of soil and Portland cement would appear to be a moisture content dryer than optimum.

Curing

The loss of moisture due to evaporation will cause a decrease in volume; this results in cracking. Keeping the moisture in the soil by proper curing could reduce early cracking and could permit the soil structure to gain sufficient strength, by proper cement hydration, to resist the volume change due to subsequent drying (12).

Temperature Differential

As previously stated, the temperature differential that exists in a base may be as great as 40 degrees F. depending on the time of the year and location. This temperature differential induces stresses that could cause shrinkage cracking. Some of the factors which have been attributed to a temperature differential are as follows (12):

1. Accelerated hydration on the upper surface due to the high temperatures.

2. Expansion and contraction of the soil resulting in a warping action.

3. The high temperatures on the upper surface forcing the moisture to a cooler region at the bottom of the slab.

Condition of Restraint

If an expansive clay is to be stabilized with ChemComp cement and sufficient restraint, whether by an internal or external method, is not provided, cracking could occur if the expansion is great enough. Also if the expansive cement contains too much of the expansive component (Calcium Sulfoaluminate), then excessive expansion could occur causing cracking if sufficient restraint is not provided. This type of cracking is caused by tensile stresses being built up within the base course section, and the cracks would probably form near the middle one-third of the section.

Surface Area

When investigating expansive cements, surface area effect is of particular concern when conducting laboratory tests on test specimens which are different in size than the actual size of the base course section. By varying the surface area of the test specimens in this research from a rectangular shape surface area to a square shape surface area, a different pattern of cracking could occur. The square specimen would also be more representative of what actually exists in the field.

Summary

All of the factors discussed may contribute to the cracking which a soil cement base exhibits. It is difficult to evaluate the factors separately since they are all to some extent dependent on one another. In this experiment, it was attempted to control these factors and observe the cracking which took place using Type I Portland cement; then, employing the same factors, a study was made to see if the cracks could be eliminated or reduced by using ChemComp - shrinkage compensated cement.

Based on these factors, four primary tests were devised; these tests were designated as Test Series No. I through Test Series No. IV. Test Series No. I was designed to show the difference in cracking between Type I Portland cement and expansive cement with the test specimens having moisture retention; e.g., the samples were ideally cured. Test Series No. II was devised to illustrate the difference in cracking between the same two types of cement stabilized soils with the test specimens having no moisture retention; e.g., the samples were uncured. Test Series No. III was designed to observe the effect of restraint when using an expansive cement for stabilizing soils by comparing the difference in cracking which occurs between specimens restrained to prevent expansion on all sides except the top and specimens which were unrestrained. Test Series No. IV was devised to observe the effect surface area might have on the expansive properties of expansive cement and also to compare the cracking which might occur.

Supplementary tests were performed to investigate the difference in strength, durability, density and curing of Type I Portland cement and ChemComp cement. In all of the tests, the cement content was varied while using the Standard Proctor Compaction effort (12,750 ft.lbs./cu.ft.). These tests will be described in detail later.

CHAPTER II

DESCRIPTION OF MATERIALS AND TESTING EQUIPMENT

Soil

The soil used in this experiment was obtained from Decatur, Georgia. The soil was a residual, rusty brown, well-graded, micaceous silty sand and was obtained from the B horizon. The soil had a liquid limit of 52 per cent and a plasticity index of 16 per cent; this indicated high compressibility and medium plasticity [(2)].

A mineral analysis was performed on the fines in the soil in order to identify the clay minerals present. The results of this analysis showed that the fines contained approximately 60 per cent kaolinite and 40 per cent biotite (black mica); an undetermined percentage of the biotite had weathered forming vermiculite, a weathered form of mica that expands to many times its original volume when heated because of its high water content [(14)]. An attempt was made to perform a mineral analysis on a more representative sample of the soil rather than just the fines, but the results obtained were erratic. The soil possessed a relatively high hygroscopic moisture content (9 to 17 per cent); the reason for this could be the presence of vermiculite which has a high affinity for water. A description of the soil is given in Table 1; the grain size distribution is shown in Figure 1, and the moisture-density curve is shown in Figure 2.

Physical Tests

After obtaining the soil, only the portion passing a No. 4 United

States Standard Sieve was placed in containers for use in the experiment.

The following standard tests were performed on the soil for identification and classification:

1. Grain size analysis as specified in ASTM designation 422-63.

2. Plastic limit as specified in ASTM designation 424-59.

3. Liquid limit as specified in ASTM designation 423-61T.

4. Specific Gravity as specified in ASTM designation 824-58.

5. Moisture-Density relationship as specified in ASTM designation 698-64T.

6. Volume Change as specified by Georgia Highway Department Specifications, Volume II - Article 800.09

Other standard tests performed throughout the experiment were:

1. Moisture content tests as specified in ASTM designation 2216-63T.

2. Unconfined Compression tests as specified in ASTM designation 1633-63.

Admixtures

The admixtures used in this experiment were Type I Portland cement and ChemComp - shrinkage compensated cement. The chemical composition of these admixtures as reported in Portland Cement Association publications is given in Tables 2 and 3 [11,12].

Testing Equipment

Compaction Mold

The compaction mold was rectangular in shape with the dimensions of 6 in. x 6 in. x 18 in.. The mold was constructed of 6 inch steel channel with a 3 in. x 3 in. steel angle used for the sleeve; the purpose

Table 1. Properties of the Micaceous Silty Sand

Liquid Limit (%)	52
Plastic Limit (%)	36
Plasticity Index (%)	16
Optimum Moisture Content, Standard Proctor, (%)	29
Specific Gravity	2.71
Grain Size (% Passing U.S. Standard Sieve No.)	
4	100.0
10	97.0
40	70.0
60	55.0
100	41.0
200	27.0
MIT Classification	
Sand (%)	70
Silt (%)	25
Clay (%)	5
Volume Change	
Swell (%)	27.4
Shrinkage (%)	3.0
Total Volume Change (%)	30.4
Soil Classification	
B. P. R. Classification	A-2-7
Unified Soil Classification	SM

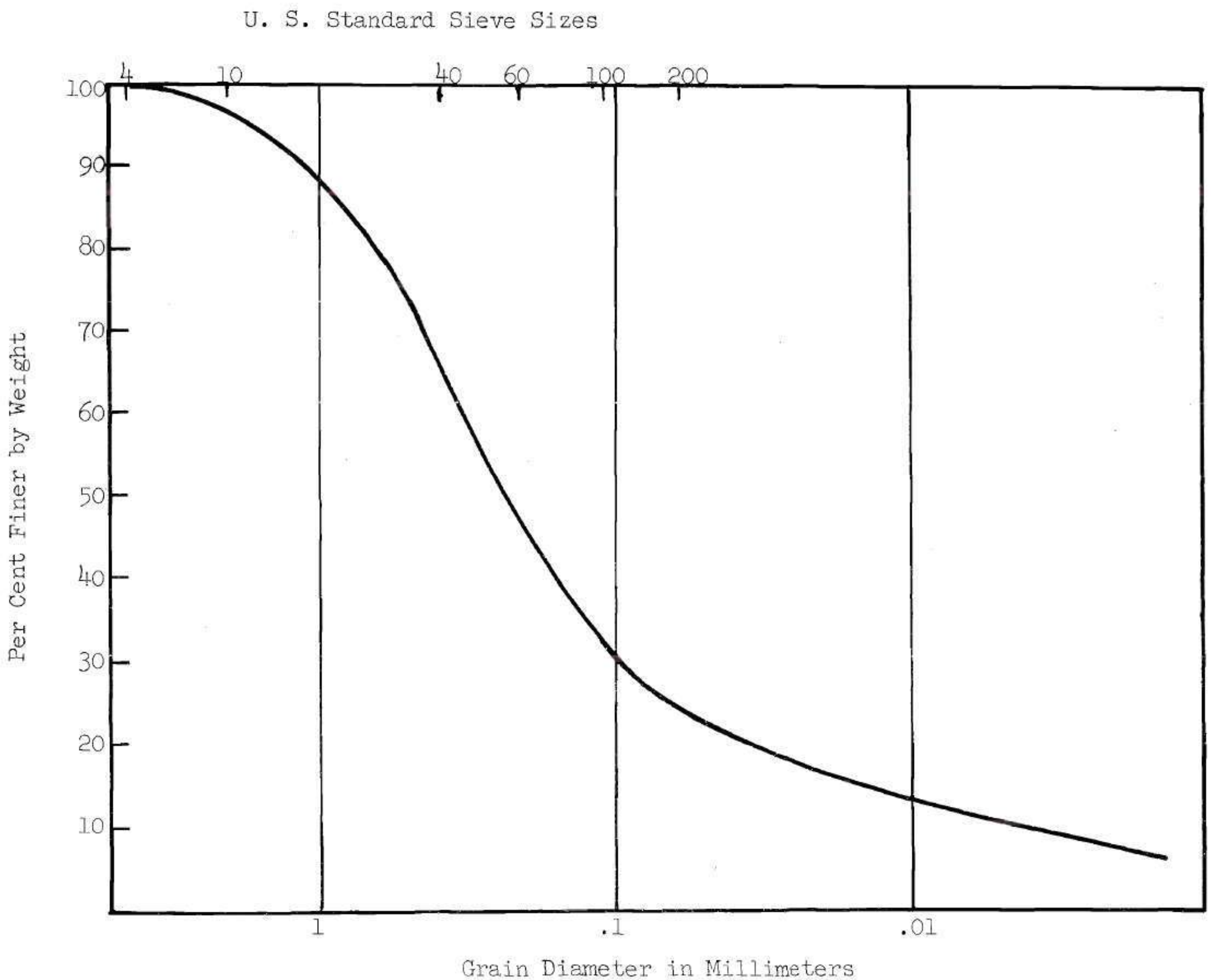


Figure 1. Grain Size Distribution Curve for the Micaceous Silty Sand

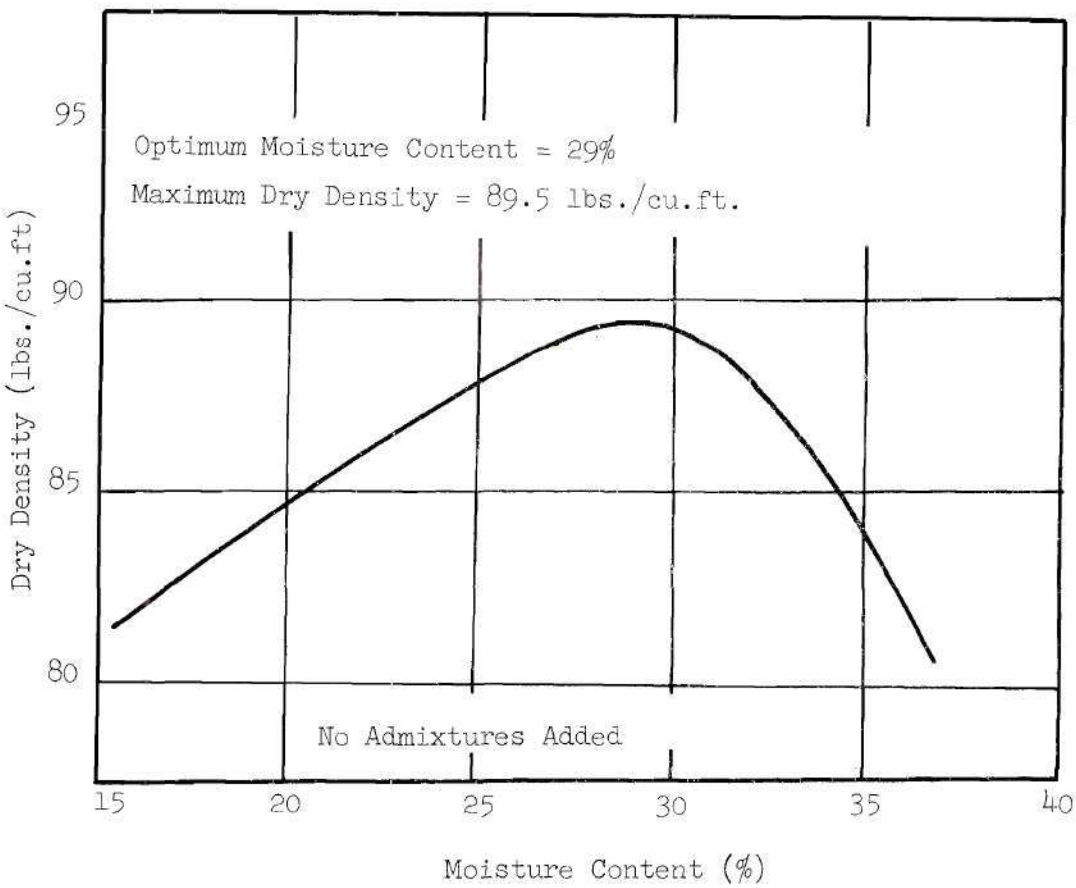


Figure 2. Moisture-Density Curve for the Micaceous Silty Sand; Standard Proctor Compaction

of the sleeve was for compacting the top layer of the soil cement mixture. This mold is shown in Figure 3.

Molds for Restrained Test

Three molds were necessary for the restrained test since the samples were retained in the molds while being cured. One of the molds used was the one described above; the other two were similar, but they had previously been constructed of 3/8 inch plate and were 24 inches in length. Three 3/4 inch plywood blocks were cut and fitted in one end of each mold to reduce the length of the compacted specimen to 18 inches.

Molds for Surface Area Test

Three molds were needed for compacting the surface area test specimens; these molds were 18 in. x 18 in. x 8 in. high. The molds were constructed of 3/4 inch plywood with large clamps placed on the corners and near the center of the mold to hold the samples secure while compacting. These clamps were not removed from the restrained ChemComp specimen.

Mixing Equipment

The soil, cement and water needed for the samples were blended with a Read Standard Grant mixer equipped with a hook blade. The mixer is shown in Figure 4.

Compaction Equipment

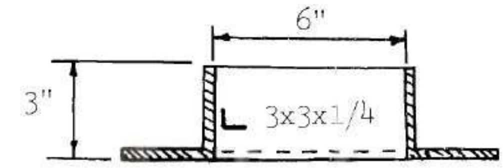
The 6 in. x 6 in. x 18 in. samples were compacted with a modified Rainhart mechanical compactor equipped with an 11 pound 1 in. x 5 7/8 in. rectangular-faced hammer. The compactor was calibrated to the Standard Proctor Compactive effort (12,750 ft.-lbs./cu.ft.). The number of blows required per 2 in. layer as computed from the energy equation was 125 blows. However, previous experimentation [12] has shown that 123 blows per

Table 2. Chemical Composition of Type I Portland Cement

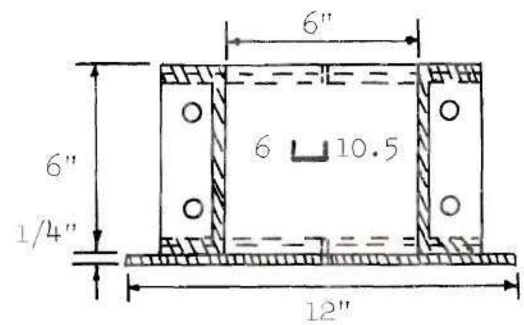
Chemical Composition, %	
Silicon dioxide, SiO	20.46
Ferric oxide, Fe_2O_3	2.44
Aluminum oxide, Al_2O_3	5.90
Sulfur trioxide, SO	2.08
Calcium oxide, CaO	62.87
Magnesium oxide, MgO	4.18
Insoluble residue	0.30
Loss on ignition	1.38
Specific surface area, Blaine (sq. cm/gm)	3464

Table 3. Chemical Composition of ChemComp Cement

Chemical Composition, %	
Silicon dioxide, SiO_2	19.21
Ferric oxide, Fe_2O_3	4.03
Aluminum oxide, Al_2O_3	7.14
Sulfur trioxide, SO_3	3.58
Calcium oxide, CaO	63.15
Magnesium oxide, MgO	1.09
Insoluble residue	0.29
Loss on ignition	1.33
Specific surface area Blaine (sq. cm/gm)	3260
Free Calcium oxide, CaO	3.52
Sodium oxide, Na_2O	0.09
Potassium oxide, K_2O	0.43



Sleeve



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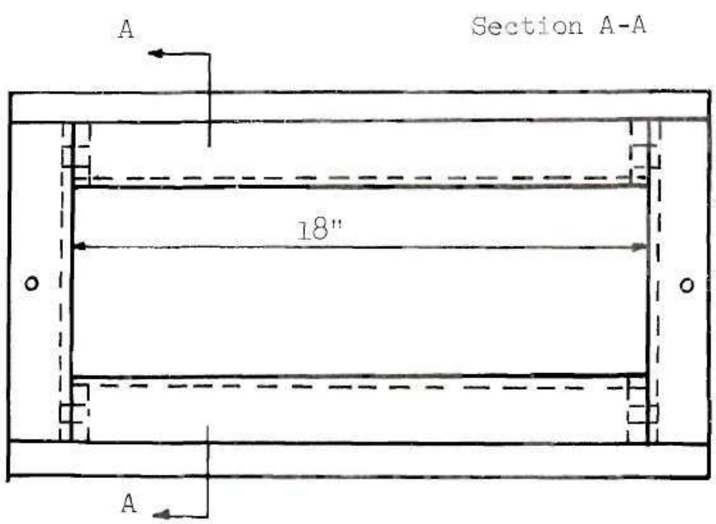

Plan

Figure 3. Test Specimen Mold

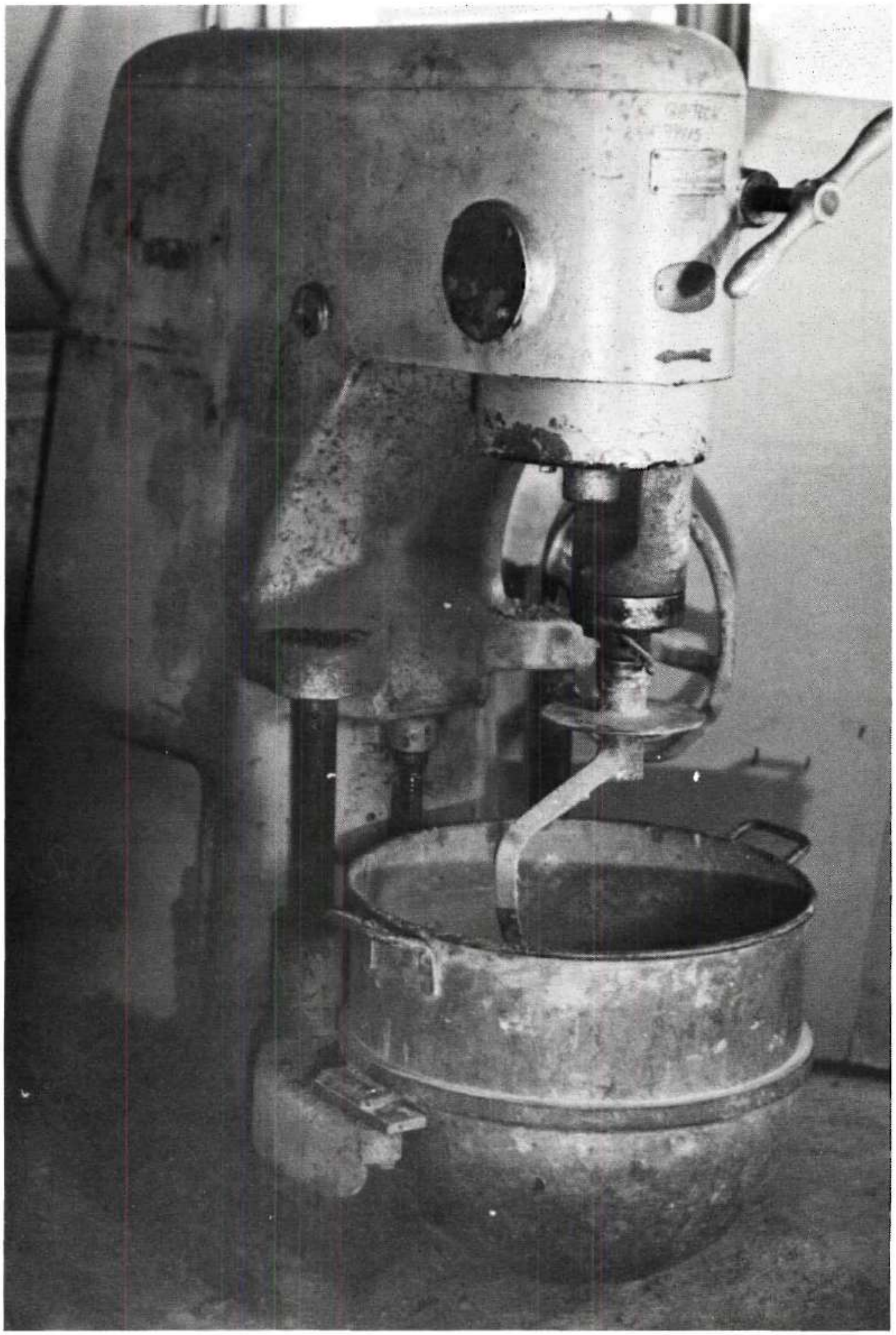

Figure 4. Read Standard Grant Mixer Used for Specimen Preparation.

Figure 5. Modified Rainhart Mechanical Compactor.

layer produced the same densities as the Standard Proctor energy level. Therefore, 123 blows per layer from a height of 12 inches above the surface was used for each of three 2 inch layers of the specimen. The compactor mounted with the mold is shown in Figure 5.

Temperature Gradient Apparatus

The samples, after compaction and removal from the molds, were placed in a temperature gradient apparatus which was constructed with space for seven samples. Five spaces had a width of approximately 6 inches so the samples would be restrained laterally for a height of 3 inches while another space could accommodate two samples for unrestrained tests. The five 6 inch spaces were restrained at one end by a 5 7/8 in. x 5 7/8 in. x 1/4 in. thick board pressed against five previously molded 6 in. x 6 in. x 18 in. specimens which fit tightly in the spaces and could not be moved longitudinally. At the other end, the samples were restrained by a 1 1/2 in. x 15 in. x 1/4 in. thick flat bar which was bent into a 90° angle; a hole was drilled in the flat bar at a position near the center of the end of the specimen and a 6 inch screw was inserted in the hole. This screw pressed against a 5 7/8 in. x 5 7/8 in. x 1 in. thick board which pressed firmly against the specimen. The flat bar was attached to the table by a C-clamp. This procedure allowed the samples to be firmly restrained at the ends.

From the AASHO Road Test (15), temperature gradient measurements were made on a section of roadway near Ottawa, Illinois in late May, 1960. From these measurements, it was found that a difference in temperature of approximately 20 to 25 degrees F. existed from the surface of the pavement to a depth of 6 inches. If this data had been collected during the months of July or August, the difference probably would have been greater. Therefore, for the purpose of the investigation, a temperature difference of approximately 40° F. was maintained through each specimen.

A temperature of approximately 105° F. was maintained on the top of the specimens by 250 watt infrared bulbs while a temperature of approximately 65° F. was maintained on the bottom of the specimens. Insulation material was packed around each specimen to prevent the heat from penetrating the cooler region. The 65° F. temperature was maintained by using water cooled by two 1/3 horsepower Copeland constant temperature water bathes each having a 25 gallon insulated tank. The water was pumped from the tanks, and then circulated through metal forms. The temperature gradient apparatus is shown in Figure 6.

Compaction Equipment for Strength Specimens

The strength specimens were molded in a 2.8 in. diameter by 5.6 in. high cylindrical mold having a volume of 1/50 cubic foot [22]. The specimens were compacted using a five pound hammer falling 12 inches. Compaction was performed in three layers with 17 blows per layer which gave the Standard Proctor Compaction effort of 12,750 ft. lbs./cu.ft.. The hammer head fit inside the mold firmly, but it did not rub against the sides while compacting.

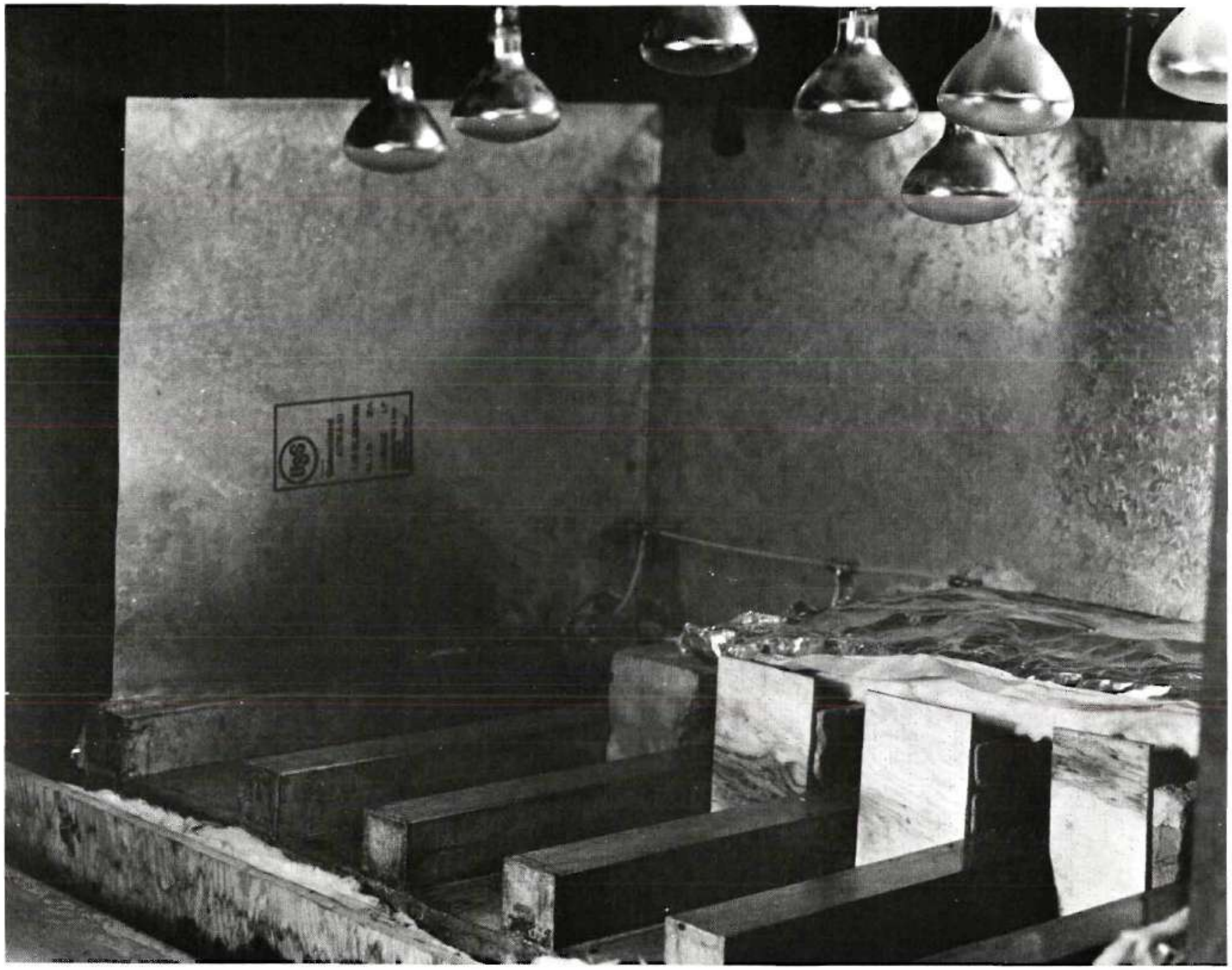

Figure 6. Temperature Gradiant Apparatus.

CHAPTER III

TESTING PROCEDURES

Description of Primary Tests

Test Series No. I

To observe the difference in cracking using Type I Portland cement and ChemComp cement with the moisture content either 3 per cent below or 3 per cent above optimum and the specimens having moisture retention the following test procedure was used:

1. Five specimens were compacted at a moisture content 3 per cent below optimum employing five different cement contents while using Type I Portland cement. The cement percentages used were 0,3,6,9 and 12.

2. After compaction, the specimens were trimmed, removed from the mold, weighed, and wrapped with saran wrap for curing.

3. The specimens were immediately placed firmly in the temperature gradient apparatus which provided them with lateral restraint for a height of 3 inches; the ends of the specimens were then restrained. The samples were then subjected to a temperature differential of approximately 40 degrees F. from the top to the bottom of the specimens for approximately 8 hours per day for 7 days.

4. After 6 days, the saran wrap was removed from the surface of the specimens, and the moisture from the specimens was allowed to evaporate during the last day.

5. After 7 days, the specimens were removed from the temperature gradient apparatus, and the saran wrap completely removed. Photographs

were then made of the specimens.

6. The five specimens were then placed out-of-doors completely unrestrained and subjected to atmospheric conditions for a period of 21 days. During the testing months of June and July, the temperatures ranged from 70 to 96 degrees F. and the rainfall was approximately normal at an average of 4.25 inches per month for the Atlanta area.

7. For the specimens which cracked using Type I Portland cement and the moisture content 3 per cent below optimum, the process described in steps 1 thru 6 were repeated making new specimens except this time using ChemComp cement. Photographs were made of these specimens, and the difference in cracking was compared. These specimens were also placed out-of-doors completely unrestrained.

8. After observing cracking at a moisture content dryer than optimum using both types of cement, five specimens were compacted at a moisture content 3 per cent above optimum employing the same cement contents as mentioned in step 1 and following the same procedure as outlined in steps 2 thru 6. After 7 days, photographs were made of these specimens, and they were placed out-of-doors completely unrestrained.

9. For the specimens which cracked using Type I Portland cement and the moisture content 3 per cent above optimum, the process described in steps 1 thru 6 were repeated making new specimens using ChemComp cement. Photographs were made of these specimens, and the difference in cracking was compared. The specimens were then placed out-of-doors completely unrestrained.

Test Series No. II

To observe the difference in cracking using the two types of cement with the moisture content at optimum and the specimens having no moisture retention the following test procedure was used:

1. Four specimens were compacted at the optimum moisture content employing cement contents of 3,6,9 and 12 per cent while using Type I Portland cement.

2. The specimens were trimmed, removed from the mold, and weighed. Then steps 3,5 and 6 were employed on Test Series No. II specimens exactly as described in Test Series No. I.

3. After observing the cracking which occurs at optimum moisture content using Type I Portland cement, four more specimens were compacted with everything identical to the first set except that ChemComp cement was used. Photographs were made of these specimens, and the difference in cracking which occurred between the two types of cement was compared. The specimens were then placed out-of-doors completely unrestrained.

Test Series No. III

This supplementary study was performed to observe the effect of restraint when using an expansive cement by comparing the difference in cracking which occurs between specimens restrained to prevent expansion on all sides except the top and specimens which were unrestrained. To observe this, ChemComp cement was used with the moisture content 3 per cent below optimum. The cement percentages used were 6,9, and 12 per cent. The following procedure was used:

1. Three specimens were compacted, trimmed, removed from the mold, weighed, and wrapped with saran wrap.

2. Two of the specimens were accurately measured at different sections to the nearest 1/32 inch. This was to see the amount of expansion which would occur after 7 days and help to understand the expansive prop-

erties of ChemComp cement.

3. The specimens were then placed in the temperature gradient apparatus in the section which could accommodate unrestrained samples, and subjected to a temperature differential of 40 degrees F. for 8 hours per day for 7 days.

4. After 6 days, the saran wrap was removed from the surface of the specimens, and the moisture from the specimens was allowed to evaporate during the last day. Final measurements were made on the two specimens which measurements had originally been made.

5. After 7 days, the specimens were removed from the temperature gradient apparatus, and the saran wrap completely removed. Photographs were then made of the specimens.

6. After observing the cracking which occurs on an unrestrained specimen, three specimens, identical to the first three were compacted, trimmed, weighed, and wrapped with saran wrap over the top surface. These specimens were retained in the molds in order to prevent expansion.

7. The specimens were then subjected to the 40 degree temperature differential, and the same procedure as used on the first three specimens was followed.

8. After 7 days, the specimens were removed from the molds, and photographs were taken; the difference in cracking which occurred was compared.

Test Series No. IV

This test was performed to observe the effect a larger surface area test specimen might have on the expansive properties of ChemComp cement and also to compare the cracking which might occur. To do this, Type I Portland Cement and ChemComp cement were used at a moisture content 3 per cent below optimum and a 6 per cent cement content. The following procedure was used:

1. Three 18 in. x 18 in. x 3 in. specimens were compacted; two of these specimens had ChemComp cement and one had Type I Portland cement. One ChemComp specimen was retained in the mold while the other was unrestrained; the Portland cement specimen was retained in the mold.

2. The three specimens were trimmed, weighed, measured, and wrapped with saran wrap.

3. The specimens were then placed in the temperature gradient apparatus, and subjected to a temperature differential of 40 degrees F. for 8 hours per day for 7 days.

4. After 6 days, the saran wrap was removed, and the moisture from the specimens was allowed to evaporate during the last day. Final measurements were made on the specimens.

5. After 7 days, the specimens were removed from the temperature gradient apparatus and the difference in cracking, if any had occurred, was compared.

Description of Supplementary Tests

Unconfined Compression Tests

This supplementary test was performed to determine the difference in strength between the soil specimens mixed with Type I Portland cement and ChemComp cement with moisture and cement contents, and curing conditions remaining the same. Specimens were made at optimum, 3 per cent below, and 3 per cent above optimum moisture content. The cement percentages used were 0,3,6,9 and 12 per cent. Each time a batch of cement stabilized soil was made for Test Series No. I or Test Series No. II, a strength specimen was molded using the compaction equipment. The specimens were extruded from the mold with a hydraulic jacking device, weighed, and placed in plastic bags. The bags were 3 in. x 5 in. x 15 in. and had been labelled to identify the sample. The bag was then sealed, and the specimens were then placed in the curing room for 7 days. During the curing period, the room was maintained at 100 per cent relative humidity and 72 degrees F.. After 7 days, the specimens were taken from the curing room, the plastic bags removed, and the specimens measured. The specimens were then tested to failure by procedure specified in ASTM designation 1633-63 in a 200,000 pound Tinius-Olson universal testing machine.

Durability Tests

This supplementary investigation was made to determine the difference in durability between specimens mixed with Type I Portland cement and ChemComp cement. The procedure devised was to expose the specimens made in Test Series No. I and II after 7 days in the temperature gradient apparatus, to atmospheric conditions for a period of 21 days. The specimens were checked periodically for additional cracking, weathering, and excessive flaking and pitting of the surface. Photographs were made of the specimens mixed with Type I Portland cement and ChemComp cement with the moisture content 3 % above optimum after 21 days of atmospheric exposure. This particular set of specimens was photographed because of the distinct difference in the durability of the specimens compacted wet of optimum.

Preparation Procedure for Specimens

1. The soil which was to be used for a particular series of tests was taken from the storage bins and four moisture content samples were taken to determine the actual hygroscopic moisture content. The soil was then placed in a large can and tightly covered with a burlap cover. After the hygroscopic moisture content had been determined, the amount of soil needed for one specimen was calculated from moisture-density data. The soil was then placed in the mixing bowl, and mixed in the Read Standard Grant mixer until homogeneous.

2. The required amount of cement was then weighed to the nearest 0.01 pound, and mixed with the soil until homogeneous. The amount of cement used was calculated as a per cent of the weight of dry soil.

3. The amount of water to be added was weighed to the nearest 0.01 pounds and slowly added while mixing to the soil-cement mixture. The amount of water used was calculated as a per cent of the total combined dry weight of the soil and cement.

4. The contents of the bowl were then mixed by the Read Standard Grant mixer for a period of approximately 60 seconds. The blade and the sides of the bowl were scraped and the contents mixed for another 60 seconds.

5. The contents of the bowl were then placed in a wheelbarrow and a strength specimen was molded. The wheelbarrow was covered with a damp burlap cover to prevent the loss of any moisture. A moisture content sample was taken and if the moisture content was more than 1.0 per cent from that desired, the specimen was discarded and a new one made.

Compaction Procedure for 6 in. x 6 in. x 18 in. Samples

1. The amount of soil needed for a two-inch layer was placed in the mold. The soil was compacted by allowing an 11-pound rectangular hammer to be dropped 123 times from a height of 12 inches above the surface of the soil (Fig. 5 shows the compaction equipment). This procedure was repeated for each of the three layers. An allowance was made for sufficient excess soil on the top layer to be scraped off level with the top of the mold. During compaction, the mold was moved horizontally to insure that the number of blows would be evenly distributed throughout the entire area of each layer.

2. The compacted specimen was removed from the mold, placed on a 4 in. x 24 in. x 3/4 in. thick plywood board and weighed to the nearest 0.1 pound. Placing the specimen on this board made placing the specimen in the temperature gradient apparatus easier. To simulate ideal field-curing, the specimens for Test Series No. I were completely sealed by wrapping them with transparent saran wrap. The specimens were then placed in the temperature gradient apparatus.

Compaction Procedure for Surface Area Test Samples

1. The amount of soil needed for a one-inch layer was placed in the square mold. The soil was compacted by hand allowing a 10 pound hammer to be dropped 240 times from a height of 18 inches above the surface of the soil which gave the Standard Proctor energy of 12,750 ft.lbs./cu.ft. The mold was divided into quarters and each quarter was given 60 blows to insure that the number of blows would be evenly distributed throughout the entire area of each of three 2 in. layers.

The top layer was then scraped off level with the top of the mold.

2. The compacted specimen was then weighed to the nearest 0.1 pound, wrapped with saran wrap, and placed in the temperature gradient apparatus.

CHAPTER IV

TEST RESULTS

Results of Primary Tests

Test Series No. I

Periodic observations made during the first few days of curing showed that more moisture collected on the inside of the saran wrap at the lower cement contents (0,3 and 6 per cent) while at the higher cement contents (9 and 12 per cent) the moisture collection became less. This was true in both types of cement and at both moisture contents. From this, it was concluded that both types of cement retain moisture when there is a sufficient amount of cement present in a soil cement mixture. Therefore, at higher cement contents, better hydration of the cement would probably occur; however, this would be dependent on the type of soil being stabilized.

The primary purpose of the 0 per cent cement samples was to determine the moisture content at the top of the sample as compared with the moisture content at the bottom of the sample after 6 days of curing. In the sample compacted 3 per cent below optimum, there was a difference of approximately 4 per cent while in the sample compacted 3 per cent above optimum, the difference was approximately 9 per cent. This difference over a distance of 6 inches in the sample is attributed to water's tendency to migrate to the cooler region at the bottom of the specimen.

For the samples compacted 3 per cent below optimum with Portland cement, cracks began to appear in the 6,9 and 12 per cent specimens with the 9 per cent specimen being the only one to exhibit surface cracks. All three of these samples showed horizontal cracks, parallel to the surface, about 1 inch from the top of the specimen and extending about one-half the length of the specimen. These cracks developed before the curing material had been removed. The surface cracks on the 9 per cent specimen developed between the sixth and seventh day of curing after the curing material had been removed. The 3 per cent specimen showed no cracks, but it possessed a very rough and irregular surface due to its low cement content. Since the 3 per cent specimen did not crack during the 7 day curing period, a 3 per cent ChemComp specimen was not molded; however, a strength specimen was made. The four specimens compacted with Portland cement at 3 per cent below optimum are shown in Figure 7.

To investigate the effect of ChemComp cement on cracking, three specimens were molded with everything remaining the same except that ChemComp cement was used. After 7 days of curing, the 6 and 12 per cent samples showed no cracks. However, the 9 per cent sample developed a surface crack, located within the middle one-third of the sample during the first 24 hours of curing. When the curing material was removed from this specimen, a very small crack was observed to exist about 1 inch from the surface and extending about one-third the length of the specimen from the end. Because of the apparent discrepancy between the 9 per cent and the 6 and 12 per cent specimens, the 9 per cent specimen was reran at a later date, and it showed no cracks after 7 days of curing. The original 3 specimens are shown in Figure 8.

At 3 per cent above optimum, all of the Portland cement specimens

Figure 7. Portland Cement Specimens, with 3, 6, 9 and 12 Per Cent Cement at 3 Per Cent Below Optimum Moisture; 7 Day Curing Period.

cracked, but the cracking did not follow a definite pattern. For example, the 12 per cent cement sample had a very severe surface crack which appeared approximately in the middle of the sample within the first 24 hours of curing; this crack extended down both sides of the sample about 2 1/2 inches. After 7 days, the crack was larger and extended down the sides of the sample about 3 to 3 1/2 inches. The 3 per cent sample developed a very fine surface crack located approximately in the middle of the specimen and extending down the sides about 1 inch; this crack also extended along the sides to the end of the specimen. These cracks formed during the last 2 days of curing, and the surface of this specimen was very rough and irregular. The 6 per cent specimen developed many small cracks over its entire surface during the last day of curing. There was also a very fine crack about 1 inch from the top of the specimen at one end and extending along the sides about 3 inches. The 9 per cent specimen showed a very small crack near the middle of the specimen, and the entire surface was very flaky. In general, the surface of all of the samples compacted with Portland cement at 3 per cent above optimum were rough, especially at the lower cement contents (3 and 6 per cent). These specimens are shown in Figure 9.

Since specimens at all four cement contents cracked to some extent using Portland cement at a moisture content 3 per cent above optimum, four new samples were molded with everything identical except that Chem-Comp cement was used. The results showed that none of the samples cracked within the first 7 days of curing, and that the surfaces were much smoother than the specimens compacted with Portland cement. These specimens are shown in Figure 10 after 7 days curing.

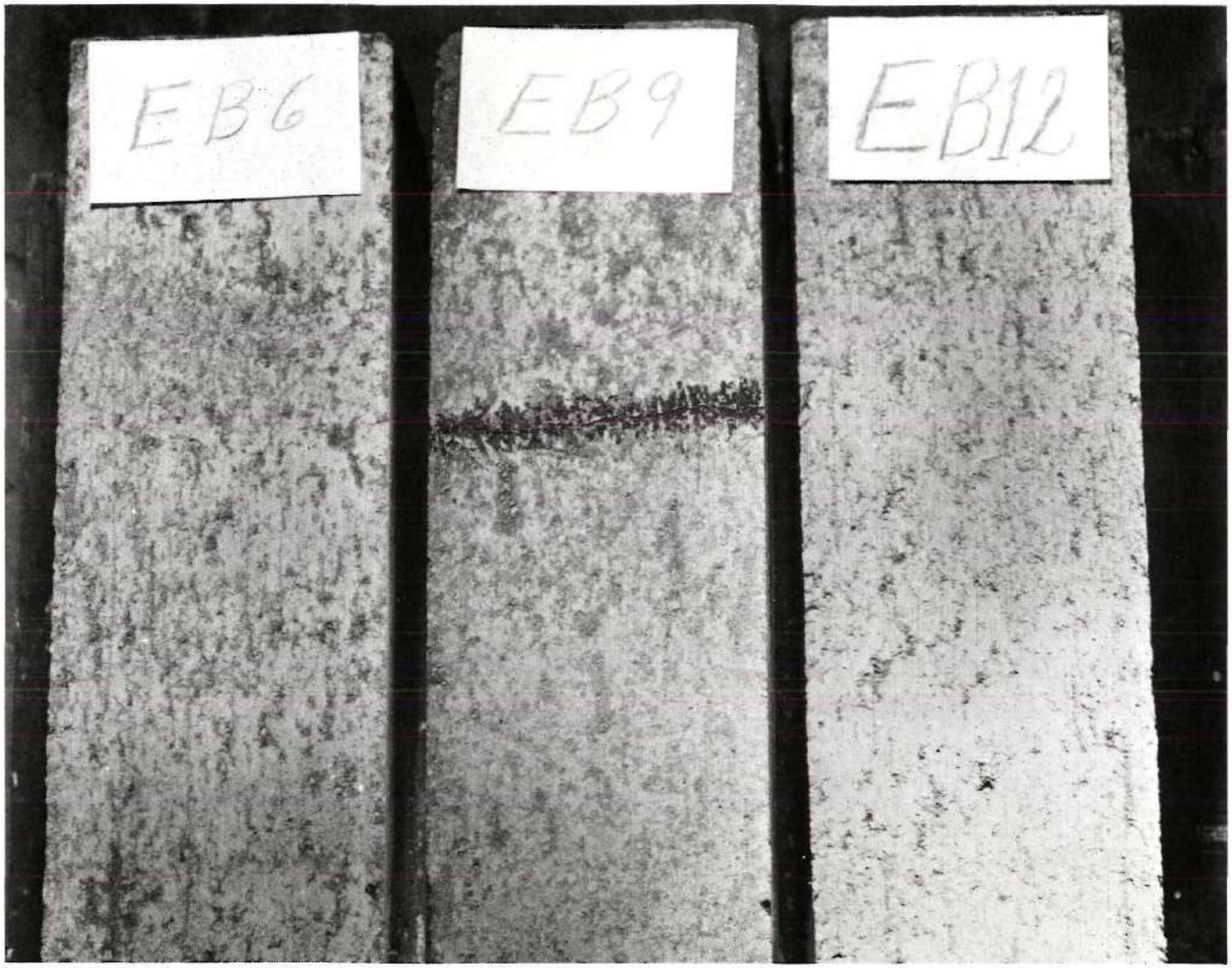

Figure 8. ChemComp Cement Specimens, with 6, 9 and 12 Per Cent at 3 Per Cent Below Optimum Moisture; 7 Day Curing Period.

Figure 9. Portland Cement Specimens, with 3, 6, 9 and 12 Per Cent Cement at 3 Per Cent Above Optimum Moisture; 7 Day Curing Period.

Graphs plotted from values given in Table 4 are shown in Figures 11 and 12. These graphs show the variation in dry density for both types of cement for Test Series No. I. At a water content of 3 per cent below optimum using Portland cement, the dry density increased as the cement content was increased until it reached a maximum at 6 per cent cement; then the dry density began decreasing to 12 per cent cement content. This illustrates that the soil density is sensitive to changing cement contents. Using ChemComp cement at a moisture content 3 per cent below optimum, the dry density remained practically constant as the cement content was varied. At a moisture content 3 per cent above optimum for ChemComp cement, the dry density remained almost constant with increasing cement contents whereas for ChemComp cement, there was a variation of approximately 3 lbs./cu.ft. in the dry density. These graphs further indicate how densities can be affected by varying moisture contents and two types of cement.

Test Series No. II

Test Series No. II was designed to investigate the cracking which occurs when the soil and either Portland or ChemComp cement was used to stabilize the soil. The mixture was compacted at the soil's optimum moisture content, and the specimens were exposed to extremely poor curing conditions; i.e., the specimens were not wrapped with saran wrap.

The results of this test series showed that all of the cracking for the Portland cement specimens occurred within the first 36 hours of exposure. The 6 per cent Portland cement specimen showed very serious surface cracking concentrated near the middle of the specimen. This crack developed within the first 24 hours and became progressively worse. The

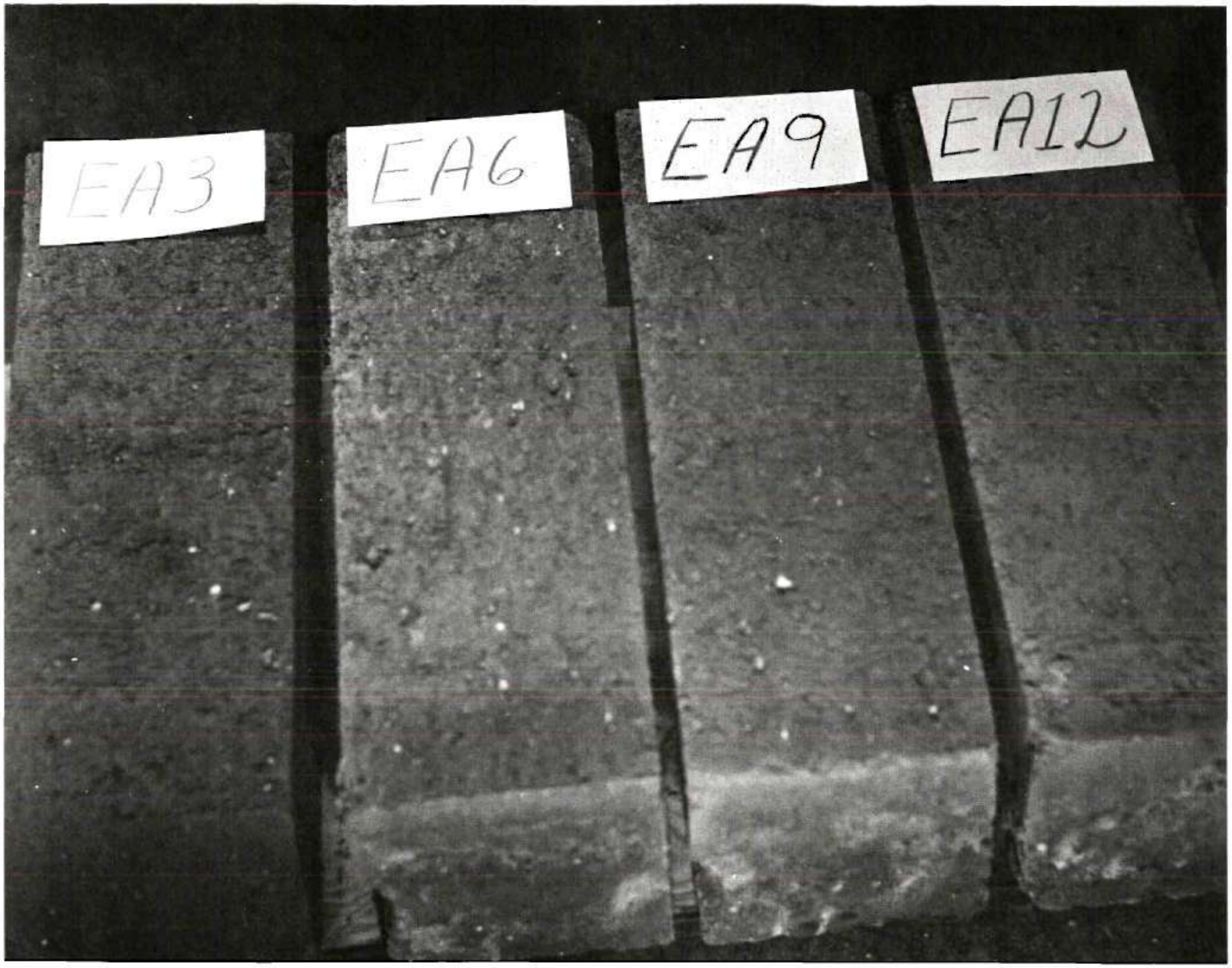

Figure 10. ChemComp Cement Specimens, with 3, 6, 9 and 12 Per Cent Cement at 3 Per Cent Above Optimum Moisture; 7 Day Curing Period.

Table 4. Test No. 1 Specimen Data

Specimen No.[1]	% Cement	Water Content (%) Desired	Water Content (%) Actual	Density (pcf) Wet	Density (pcf) Dry
PB0	0	26.0	25.1	110.0	88.0
PB3	3	26.0	25.2	119.0	95.0
PB6	6	26.0	25.5	123.0	98.0
PB9	9	26.0	25.8	120.0	95.0
PB12	12	26.0	25.3	116.0	93.0
EB3	3	26.0	25.3	119.0	95.0
EB6	6	26.0	25.3	120.0	95.5
EB9	9	26.0	25.2	117.0	93.5
EB12	12	26.0	25.6	119.0	95.0
PA0	0	32.0	32.7	116.0	87.5
PA3	3	32.0	33.0	117.0	88.2
PA6	6	32.0	31.1	118.0	90.0
PA9	9	32.0	31.2	118.5	90.4
PA12	12	32.0	31.2	118.5	90.4
EA3	3	32.0	31.5	120.0	91.4
EA6	6	32.0	31.1	120.0	91.5
EA9	9	32.0	31.3	120.5	91.8
EA12	12	32.0	32.2	120.5	91.4

Notes: (1) (P) represents Portland cement and (E) represents ChemComp cement. (B) represents 3% below OMC and (A) represents 3% above OMC.

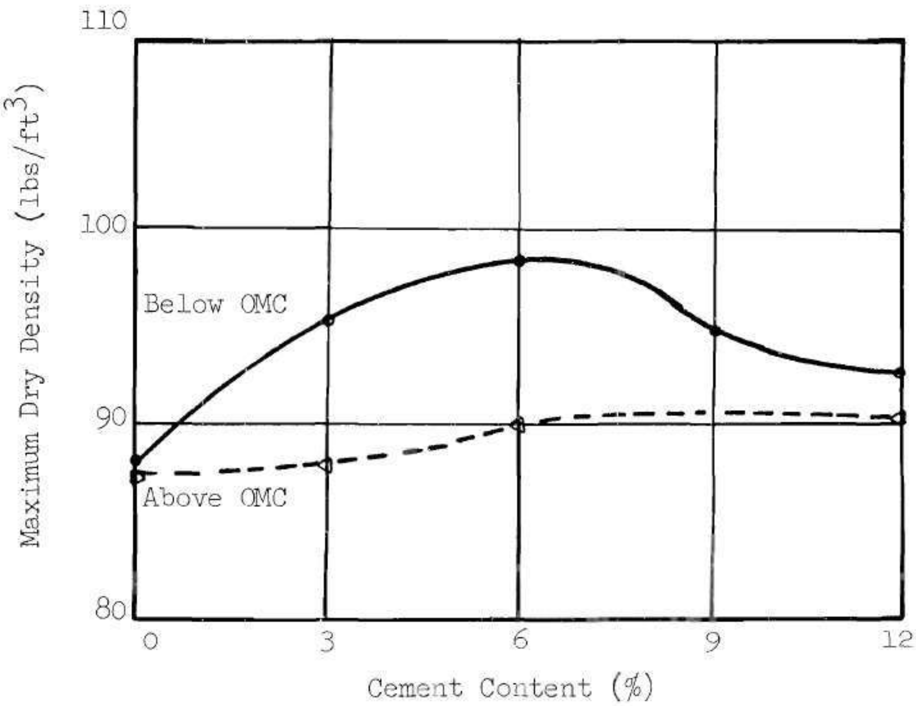

Figure 11. Influence of Portland Cement Content on Maximum Dry Density of Stabilized Soil

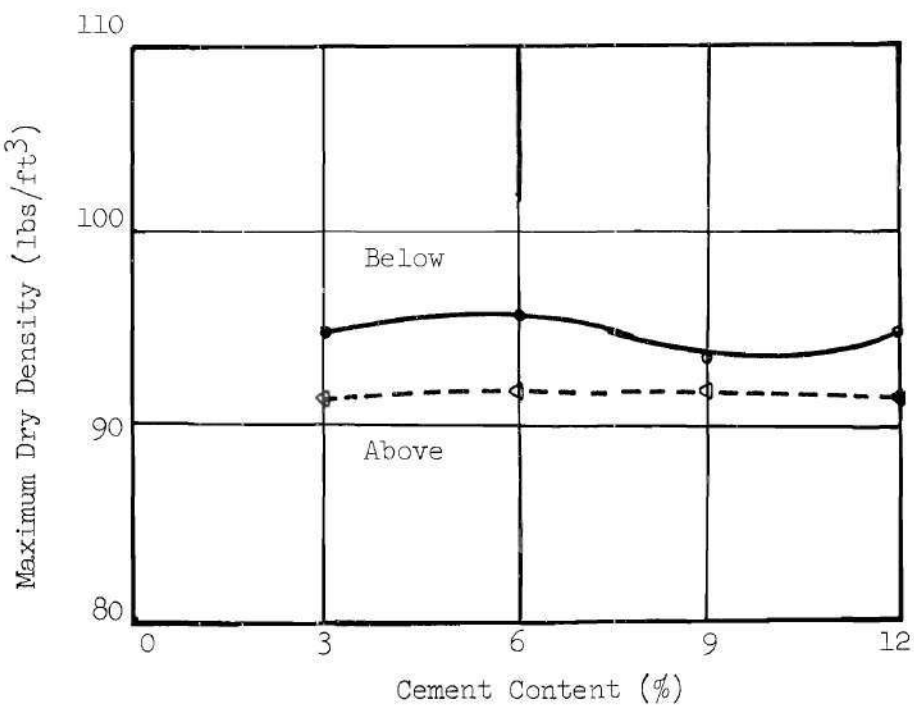

Figure 12. Influence of ChemComp Cement Content on Maximum Dry Density of Stabilized Soil

9 per cent specimen formed a surface crack also within the first 24 hours, but it was not as wide or deep as the 6 per cent specimen. The 9 per cent specimen also formed a small crack at one end of the specimen about 3 inches from the top; this crack extended along the sides, parallel to the surface, for about 3 inches. The 12 per cent sample developed a crack at one end which extended along the sides parallel to the surface about 5 inches. The 3 per cent specimen showed no cracks after 7 days. All of the specimens were very dry on the surface and had a flaky appearance after 7 days of exposure to the temperature differential; this was due to improper hydration of the cement on the upper portion of the sample since the water within the sample was allowed to evaporate into the atmosphere. These four specimens are shown in Figure 13.

For the specimens compacted with ChemComp cement, after 7 days no cracks had appeared except for the 9 per cent specimen which developed a very small crack near the corner of the specimen during the sixth day. These samples appeared in much better condition than the samples mixed with Portland cement. The surfaces were dry, but they did not have the flaky appearance which the Portland cement specimens possessed.

A graph showing the difference in Maximum dry density for the two types of cements at optimum moisture is shown in Figure 15 and was plotted from values given in Table 5. For Portland cement specimens, there was a decrease in dry density for an increase in cement content. For ChemComp cement specimens, there was an initial decrease in dry density up to 9 per cent cement then there was an increase. As previously mentioned, this type of soil is very sensitive to changing cement contents, and more testing would be necessary in order to draw a

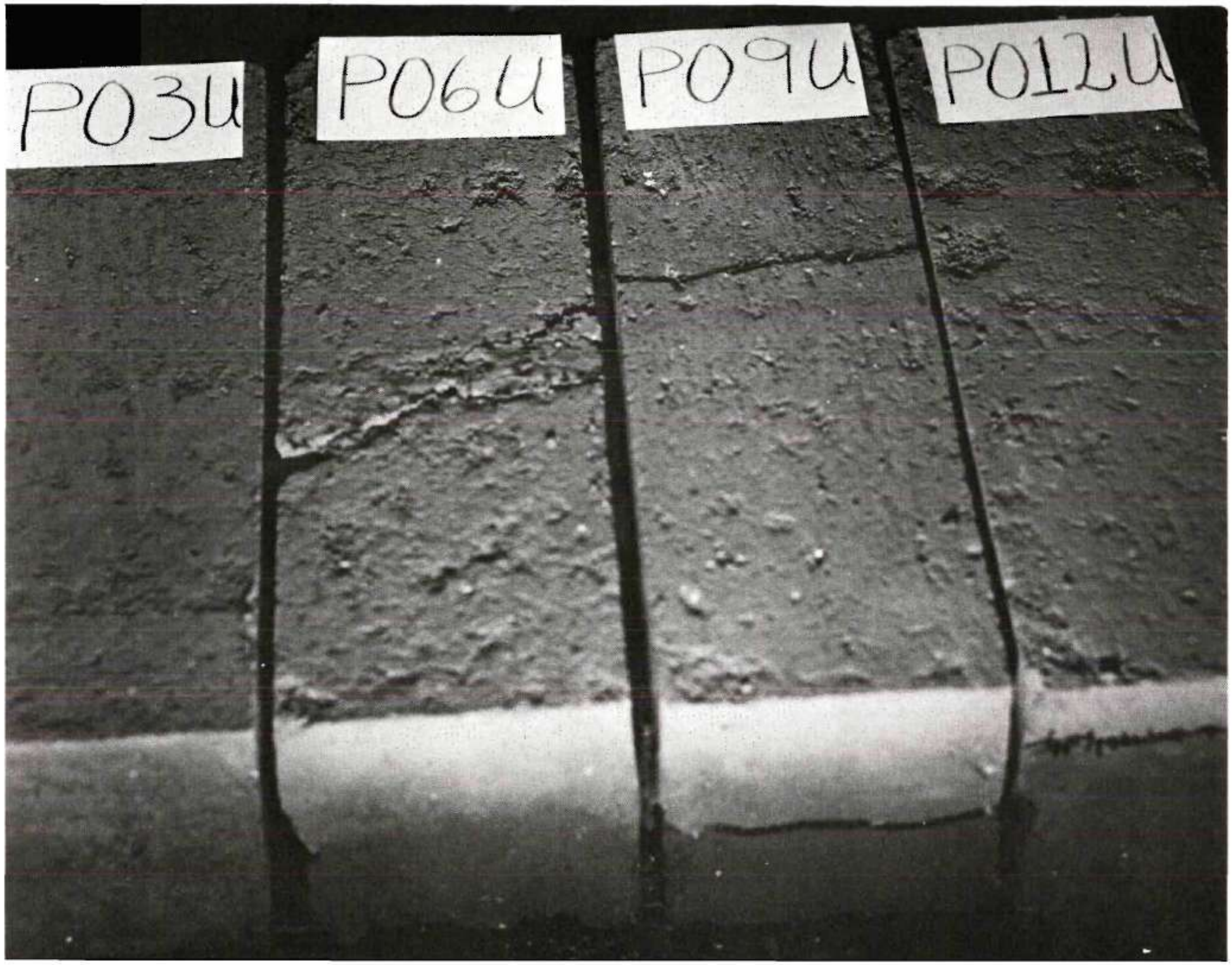

Figure 13. Portland Cement Specimens, with 3, 6, 9 and 12 Per Cent Cement at Optimum Moisture, After 7 Day Exposure to Temperature Grad-Gradiant; Improper Curing.

definite conclusion as to the variation of dry density with changes in cement content for the Portland and ChemComp cement stabilized soil.

Test Series No. III

The results of this phase of the investigation indicated that when using ChemComp cement to stabilize the soil, the condition of restraint had little effect on the amount of cracking. The 3 per cent below optimum moisture content was selected for this test because in Test Series No. I this moisture developed cracking in the original 9 per cent specimen when using ChemComp cement. Measurements were made on two of the unrestrained samples. The two specimens selected were those with 6 and 12 per cent cement content. Measurements were made initially across the width of each specimen at four different locations and along the length of each specimen at three different locations. For the unrestrained specimen with 6 per cent ChemComp cement, an average overall expansion in both directions of approximately 1/16 inch took place. For the 12 per cent specimen, an average overall expansion in both directions of approximately 3/32 inch took place.

Only one specimen in this phase of the test exhibited cracking, and that was the unrestrained specimen with 6 per cent cement. This specimen began developing two surface cracks after the saran wrap had been removed; the cracks were small, and they extended down the sides of the specimen only about 1/2 inch. Another crack formed at one end of the specimen about 1 1/2 inches from the top and extended along the sides parallel to the surface of the specimen about 5 inches; this crack was also very small. The unrestrained specimens with 9 and 12 per cent cement possessed no cracks after 7 days. The 3 unrestrained samples

Figure 14. ChemComp Cement Specimens, with 3, 6, 9 and 12 Per Cent Cement at Optimum Moisture, After 7 Day Exposure to Temperature Gradiant; Improper Curing.

Table 5. Test No. 2 Specimen Data

Specimen No.	% Cement	Water Content (%)		Density (pcf)	
		Desired	Actual	Wet	Dry
P03U	3	29.0	28.2	124.5	97.5
P06U	6	29.0	28.0	125.0	97.8
P09U	9	29.0	28.1	123.8	96.5
P012U	12	29.0	29.6	121.3	93.8
E03U	3	29.0	29.9	125.2	96.8
E06U	6	29.0	28.0	122.5	95.8
E09U	9	29.0	28.4	120.0	93.5
E012U	12	29.0	29.0	122.8	95.5

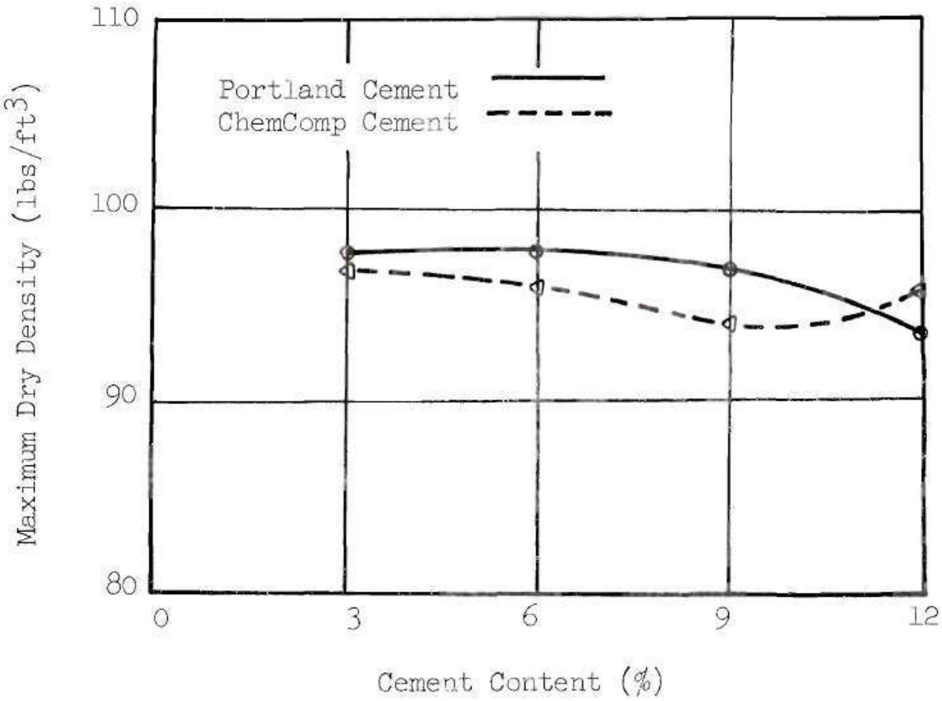

Figure 15. Difference in Maximum Dry Density between Portland Cement and ChemComp Cement Specimens at Optimum Moisture Content; Test Series No. II

are shown in Figure 16.

The three restrained specimens showed no cracks and had about the same appearance as the unrestrained samples having the same moisture and cement contents after 7 days. Of all of the tests performed on samples at 3 per cent below optimum moisture, this restrained test is the only one which showed no signs of cracking using ChemComp cement. The three restrained specimens are shown in Figure 17 after being removed from the molds.

Test Series No. IV

This investigation was made in order to observe the effects the surface area of the test specimen had on the cracking of two ChemComp cement specimens as compared with a Portland cement specimen and to observe any differences which might occur between the 18 in. x 18 in. x 3 in. samples and the 6 in. x 6 in. x 18 in. samples used in this test series. In order to bound the conditions of restraint which actually exist in the field, one ChemComp specimen was unrestrained and the other restrained. The restraint was provided by using large clamps on the corners and in the center of the specimen mold in both directions.

The Portland cement control specimen which was retained in the mold developed a series of fine cracks on the surface after the third day of curing. By the seventh day, the cracks had noticeably widened to approximately 1/16 inch in width, and followed no definite pattern. Both the restrained and unrestrained ChemComp specimens showed no cracks after 7 days. The durability as determined by visual inspection of the three specimens after 7 days was about the same not considering the cracking, and it compared quite favorably with the durability of the

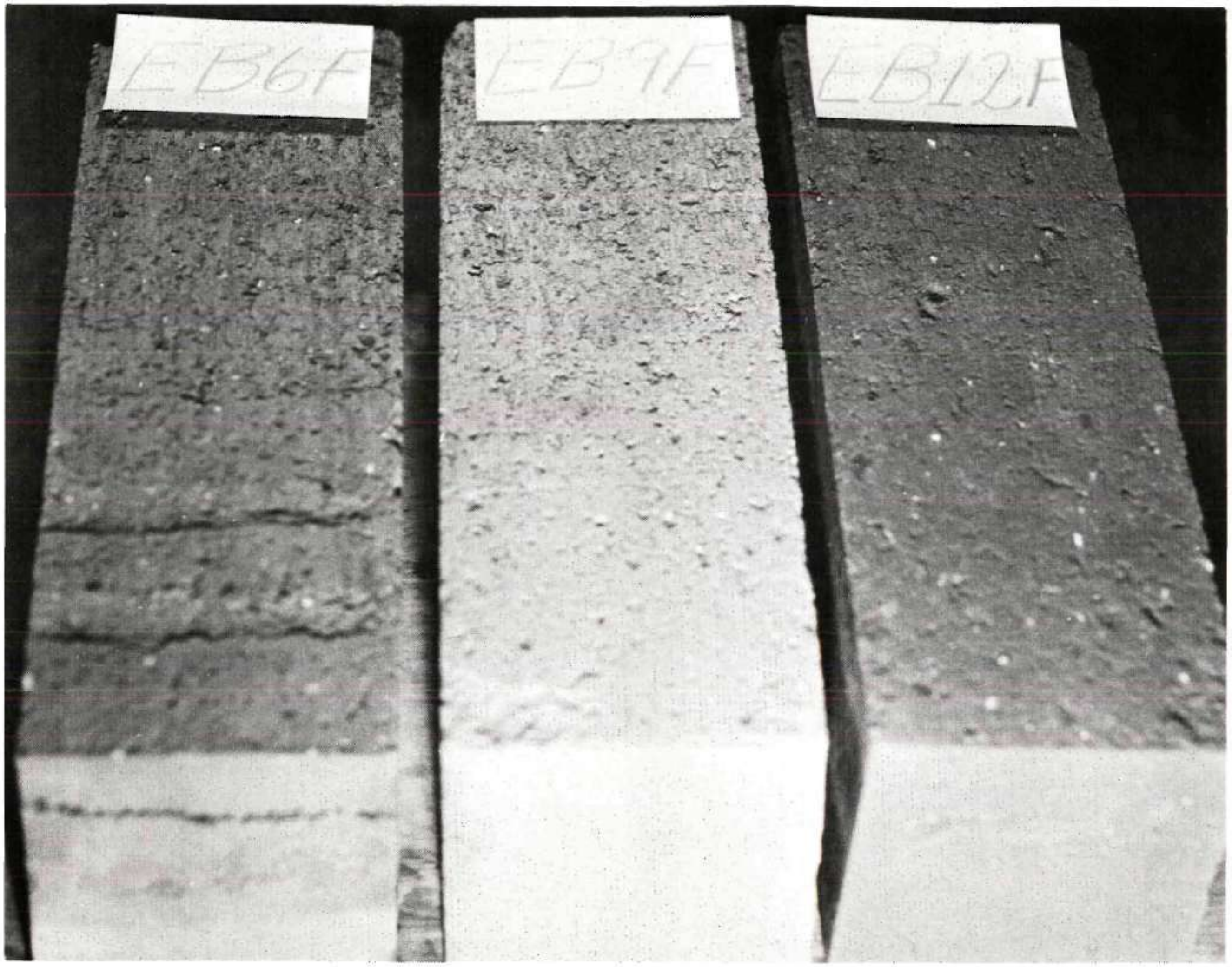

Figure 16. Unrestrained ChemComp Cement Specimens, with 6, 9 and 12 Per Cent Cement at 3 Per Cent Below Optimum Moisture; 7 Day Curing Period.

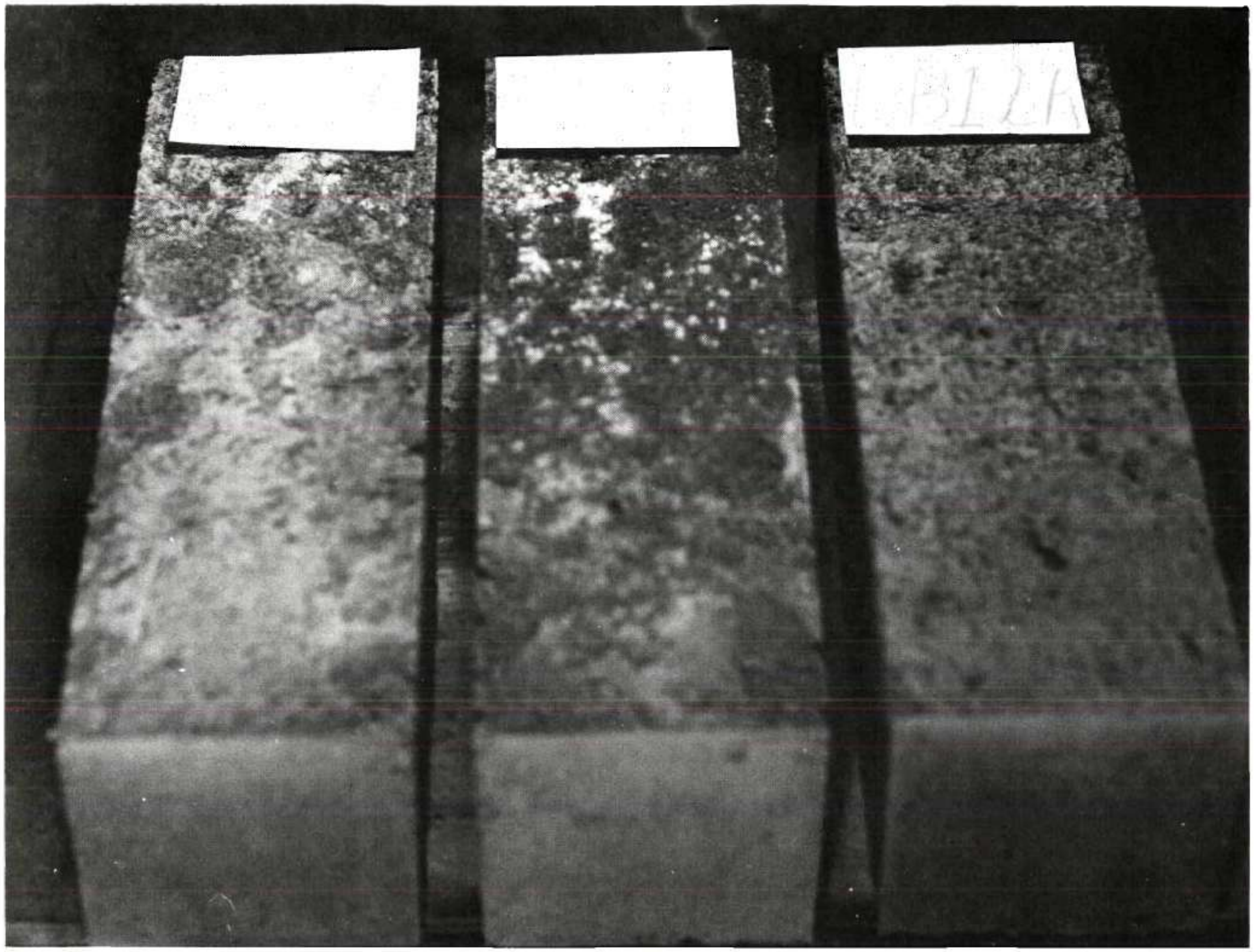

Figure 17. Restrained ChemComp Cement Specimens, with 6, 9 and 12 Per Cent Cement at 3 Per Cent Below Optimum Moisture; 7 Day Curing Period.

other specimens previously compacted at the same moisture and cement contents. Measurements were made on the Portland cement and the unrestrained ChemComp specimens at the time they were placed in the temperature gradiant apparatus. The final measurements showed that the Portland cement specimen shrunk about an average of 1/8 inch at the end and middle dimensions of the specimen while the unrestrained ChemComp specimen showed an increase of approximately the same amount; measurements were made to the nearest 1/32 inch.

Results of Supplementary Tests

Unconfined Compression Tests

This investigation was made to determine the difference in unconfined compressive strength between specimens mixed with Type I Portland cement and ChemComp cement. Figures 18 thru 20 illustrate the difference in strength between the two types of cement at 3 per cent below, 3 per cent above, and at optimum moisture content. As expected, the strength increased with an increase in cement content in all three cases. At 3 per cent below and 3 per cent above optimum moisture content, ChemComp cement samples had from 10 to 60 p.s.i. higher strength than the Portland cement samples. At optimum moisture content, the Portland cement samples had from 15 to 30 p.s.i. higher strength than the ChemComp samples. These results give an indication of the effect of unconfined compressive strength using the two types of cement; more tests would be necessary in order to reach definite conclusions.

Durability Tests

The results of this test showed a definite difference between the durability of samples mixed with Type I Portland cement and ChemComp cement. The difference was exhibited in the surface texture and general overall condition of the test specimens under investigation were those compacted in Test Series No. I and Test Series No. II. A close observation was made on the specimens after 7 days of exposure to the temperature gradiant and after 21 additional days of exposure to atmospheric conditions.

From Test Series No. I, for the samples compacted at 3 per cent below optimum moisture, the ChemComp specimens had smoother surfaces than the Portland cement specimens after 7 days. After the 21 day exposure to atmospheric conditions, the original crack in the 12 per cent Portland cement specimen continued through the entire length of the sample. Also the 12 per cent ChemComp sample developed a crack in the same location, after 8 days exposure to outside conditions, which extended only one-half the length of the specimen; the crack did not progress further after 8 days. Except for this additional cracking which occurred in the specimens having the highest cement content for both types of cement, there was no additional cracking, and there was little difference in the overall durability of the other Portland and ChemComp cement specimens as far as the surface texture and condition was concerned.

For the samples compacted 3 per cent above optimum, the ChemComp specimens exhibited much better durability than the Portland cement specimens. After 7 days exposure to the temperature gradiant, as can be observed in Figures 9 and 11, there was a noticeable difference in the surface texture of the samples. Specimens compacted at the lower

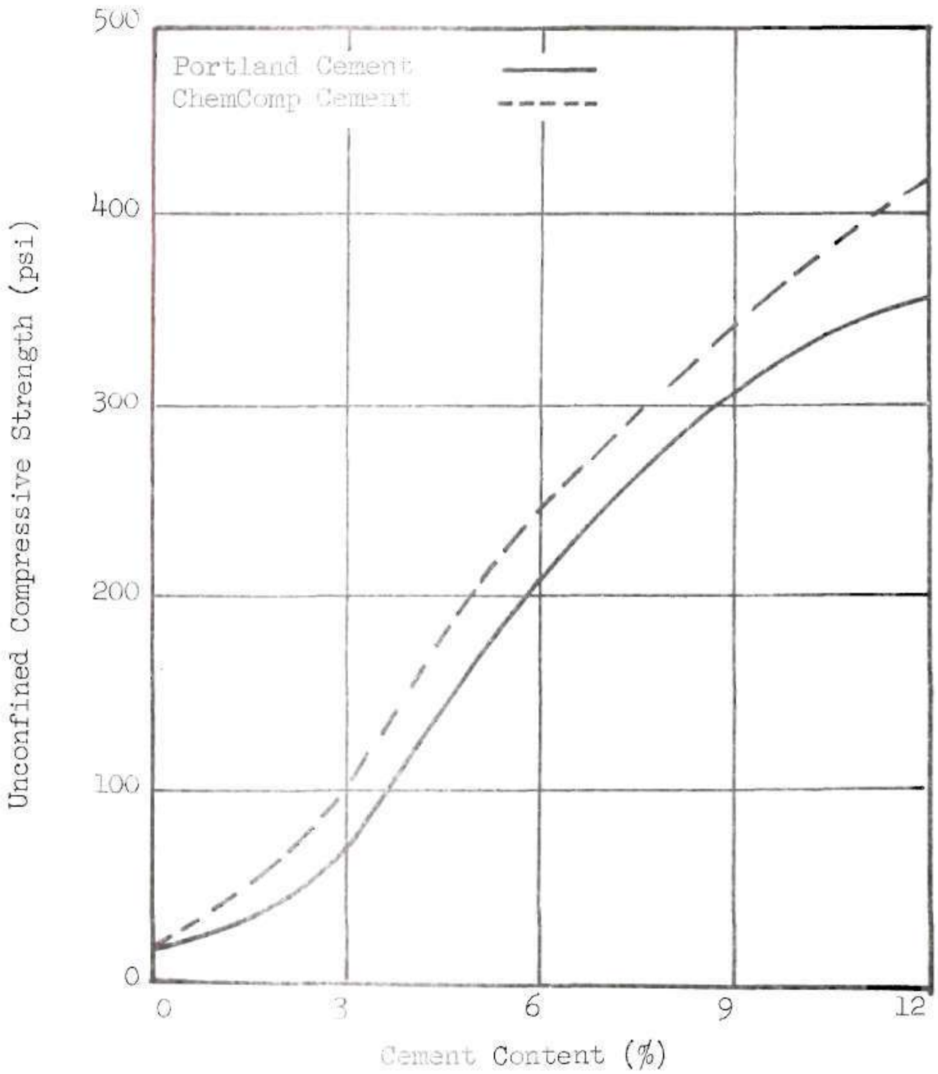

Figure 18. Difference in Unconfined Compressive Strength Between Portland Cement and ChemComp Cement at a Moisture Content 3 Per Cent Below Optimum

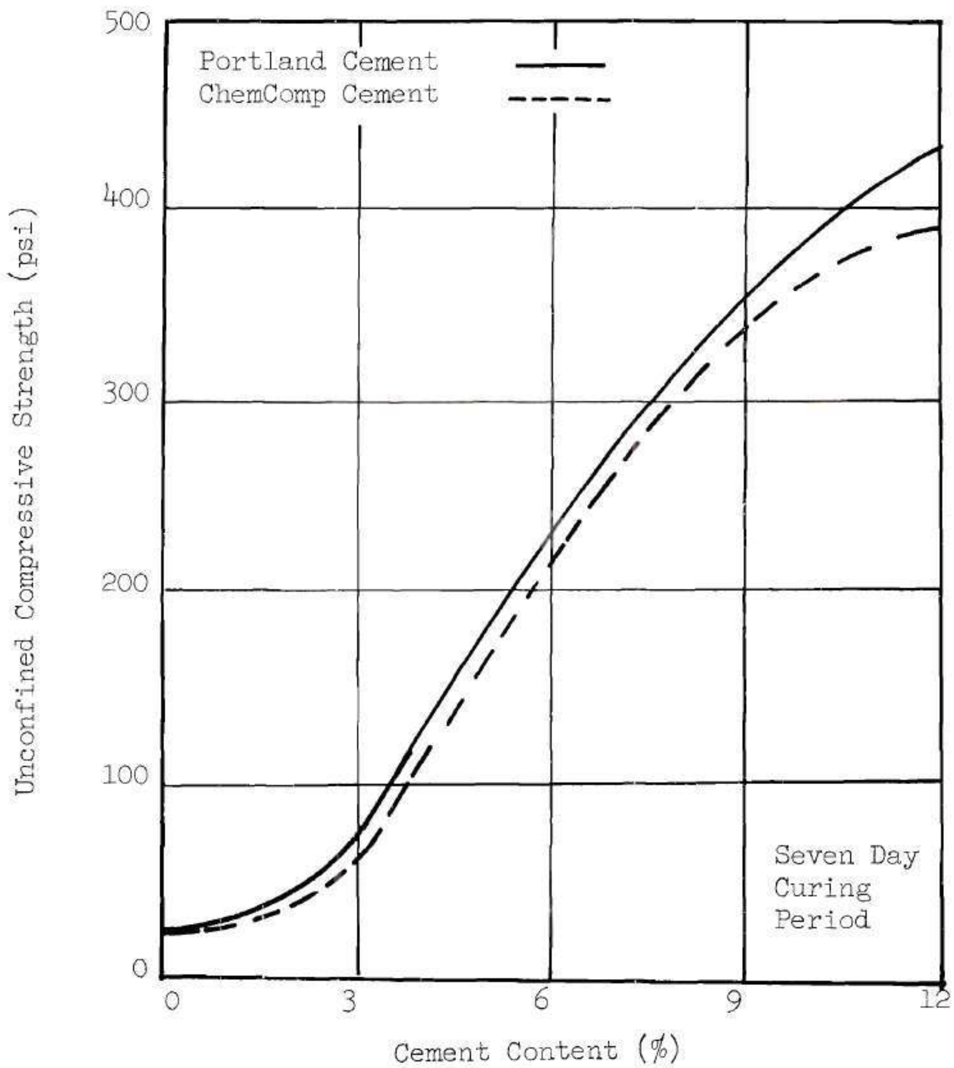

Figure 19. Difference in Unconfined Compressive Strength Between Portland Cement and ChemComp Cement at Optimum Moisture Content

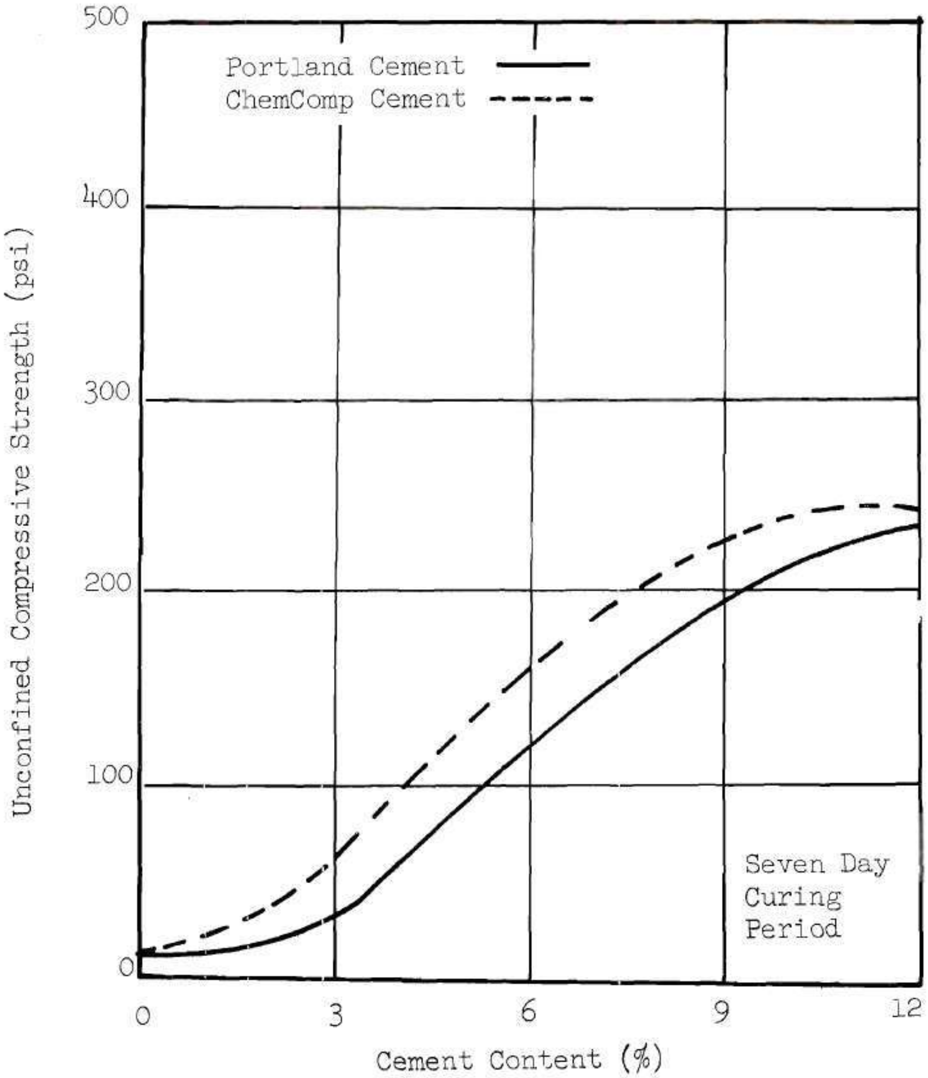

Figure 20. Difference in Unconfined Compressive Strength Between Portland Cement and ChemComp Cement at a Moisture Content 3 Per Cent Above Optimum

Portland cement contents (3 and 6 per cent) showed very rough surfaces while the ChemComp specimens were much smoother after 7 days. After 21 days of exposure to atmospheric conditions, the original cracks in the Portland cement specimens widened, and the 3 per cent specimen showed considerable weathering. All of the Portland cement samples exhibited a rough and flaky surface. In contrast, the ChemComp specimens were in much better condition. However, the 3 per cent specimen did weather some, but not to the extent as the Portland cement specimen. Figures 21 and 22 show the Portland cement and ChemComp cement specimens after the completion of 21 days exposure to atmospheric conditions.

For Test Series No. II specimens, which were compacted at optimum moisture content and not cured, the durability test results indicate the importance of proper curing. The surfaces of the Portland and ChemComp cement specimens appeared about the same (not considering cracking) after 7 days with both possessing very dry and flaky surfaces. This was primarily caused by rapid hydration of the surface which caused particles of soil cement near the surface not to adhere properly to the mass thus yielding a surface which was flaky and rough in appearance. The Portland cement samples, which cracked at an early age, developed no additional cracks, but the existing cracks did widen, and there was some heavy weathering of the sample in the vicinity of the cracks in the 6 and 9 per cent specimens. The main difference between the two sets of samples was that the ChemComp specimens never developed cracks; however, not considering the cracking, both sets of specimens showed about the same durability after 21 days of outside exposure.

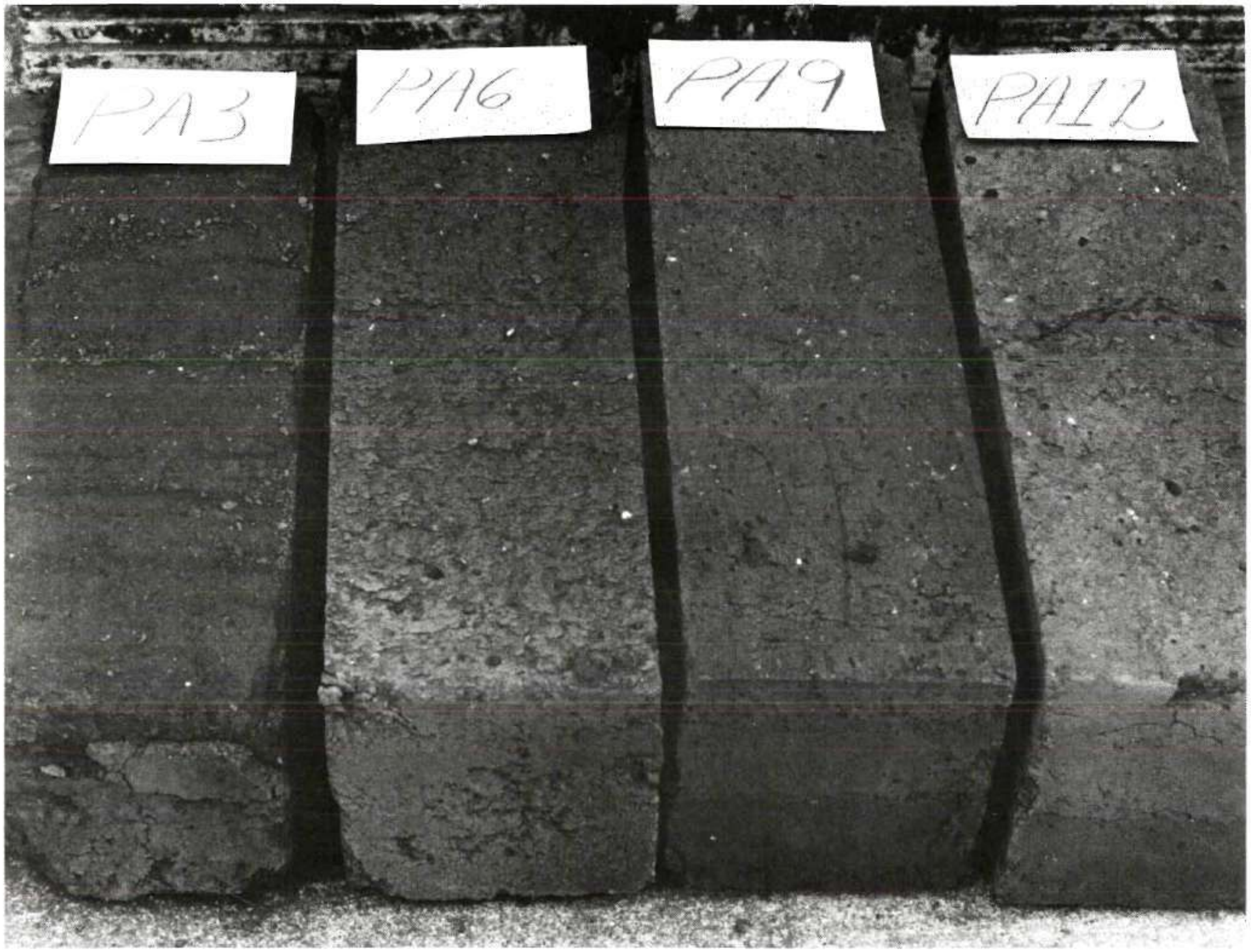

Figure 21. Portland Cement Specimens, with 3, 6, 9 and 12 Per Cent Cement at 3 Per Cent Above Optimum Moisture, After 21 Day Exposure to Atmoshperic Conditions.

Figure 22. ChemComp Cement Specimens, with 3, 6, 9 and 12 Per Cent Cement at 3 Per Cent Above Optimum Moisture, After 21 Day Exposure to Atmospheric Conditions.

Discussion of Test Results

In general, the use of ChemComp cement reduces, and in some cases eliminates, the shrinkage cracking which occurs when Portland cement is used to stabilize this particular soil. All of the ChemComp cement samples compacted in Test Series No. I, II, III and IV showed that either comparatively minor cracking had occurred, or that cracking had been eliminated entirely when comparing these ChemComp specimens with their corresponding Portland cement specimens. In both instances, most of the cracking occurred in the samples compacted with 6 per cent cement content or higher. At moisture contents 3 per cent above optimum, the ChemComp cement specimens showed an important improvement over the Portland cement specimens with respect to both cracking and durability.

The importance of proper curing when using Portland cement is illustrated when no curing membrane (Test Series No. II) was used to retain the moisture within the sample so that proper cement hydration could occur. Three of these specimens exhibited cracking within the first 36 hours of exposure to the temperature differential. This was due to the moisture within the compacted soil cement specimens being allowed to evaporate into the atmosphere. This evaporation caused rapid hydration of the samples which resulted in expansion and contraction of the surfaces of the specimens. Had proper moisture retention been provided, this early cracking probably could have been prevented or reduced by allowing the specimens to gain sufficient strength by proper cement hydration. However, the corresponding ChemComp cement specimens showed no cracks except for the 9 per cent specicement stabilized soil is capable of withstanding more severe curing conditions than Portland cement stabilized soil for this particular micaceous silty sand.

The dry density data collected in this research shows that this particular soil is very sensitive to changing cement contents. By this it is meant that no trend can be predicted as to the increase or decrease in maximum dry density for increasing cement contents. This is clearly observed when examining Figures 11, 12 and 15.

For this particular soil, restraint apparently had little effect on the amount of shrinkage cracking which occurred when using ChemComp cement. Only the 6 per cent unrestrained specimen cracked in Test Series No. III while in Test Series No. IV the 6 per cent unrestrained specimen did not crack. However, some frictional restraint may have been induced in the unrestrained surface area test specimen since the soil cement mixture was compacted directly on the bottom of the mold and only the sides of the mold were removed; i.e., the sample remained on the bottom of the mold while curing. In the field, some restraint will always be provided on the bottom of a base course section where the base comes in contact with the subbase or subgrade. This will occur whether the base course section is restrained laterally, longitudinally or both. However, completely restrained (laterally and longitudinally) ChemComp specimens of the soil investigated appeared to have a better overall appearance, and none showed any signs of cracking after 7 days. Therefore, it is concluded that if some type of restraint, either external or internal, is provided to a section of this soil stabilized with ChemComp cement, cracking will probably not occur.

The surface area test (Test Series No. IV) showed that the specimen size had little or no effect on the capability of ChemComp cement to compensate for the shrinkage due to drying when using it to stabilize this soil. The results of this phase of the investigation showed that the unrestrained ChemComp specimen in Test Series No. IV which had 6 per cent cement content showed approximately twice the expansion the 6 per cent unrestrained ChemComp specimen exhibited in Test Series No. III. This illustrates that the expansion which occurs when stabilizing this soil with ChemComp cement is in proportion to the surface area of the laboratory test specimen being used. Research should be conducted to see if enough expansion would occur on an actual size base course section in order to compensate for the shrinkage which will occur due to drying.

There is little difference in the strength of ChemComp cement and Portland cement specimens when the mixture of soil, cement and water is compacted at the soil's optimum moisture content. However, at moisture contents above or below the soil's optimum moisture, ChemComp specimens exhibited the higher strengths. The strength difference is especially noticeable in the lower cement content specimen at a moisture content 3 per cent above optimum.

When soil cement is compacted at optimum, or 3 per cent above the soil's optimum moisture, ChemComp cement appears to give better durability than Portland cement for this particular soil. This is particularly true at the lower cement contents.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

From an evaluation of the test results, as given in Chapter IV, the following conclusions were made:

1. ChemComp cement apparently has the ability to reduce or eliminate shrinkage cracking when used to stabilize a micaceous silty sand.

2. ChemComp cement stabilized soil specimens are capable of withstanding more severe curing conditions than Portland cement stabilized soil specimens.

3. Restraint apparently has little effect on the amount of cracking which occurs when using ChemComp cement to stabilize this soil in the laboratory.

4. However, if some type of restraint, either internal or external, is provided to an actual size base course section of this soil stabilized with ChemComp cement, cracking probably will not occur.

5. The surface area test showed that the specimen size had no detrimental effect on the capability of ChemComp cement to compensate for the shrinkage due to drying when using it to stabilize this soil.

6. There is little difference in the strength of ChemComp cement and Portland cement specimens when the mixture of soil, cement and water is compacted at the soil's optimum moisture content.

7. When soil cement is compacted at optimum, or 3 per cent above the soil's optimum moisture content, ChemComp cement appears to give

better durability than Portland cement for this particular soil.

From this research, it is recommeded that:

1. Research, similar to this, be performed to observe the ability of ChemComp cement to reduce or prevent cracking using a number of different types of soil.

2. An extensive investigation be made on different sizes of soil cement specimens using ChemComp cement in an attempt to find a relationship between the size of the specimen and the expansion which occurs while varying the cement content.

3. An investigation be conducted to determine the difference in the stress-strain relationships using ChemComp and Portland cement for different types of soil while varying the moisture contents of the moisture contents of the mixture.

4. An extensive study be made on different types of restraint which can be provided to a soil cement base using large surface area specimens in an attempt to produce a crack-resistant base course.

5. Research be conducted on an actual size base course section using ChemComp cement to stabilize the soil to see if enough expansion will occur to compensate for the shrinkage due to drying.

6. An economic study should be made for pavements using cement stabilized micaceous silty sand bases or subgrades to determine whether a longtime savings can be achieved by stabilizing soils with ChemComp cement rather than Portland cement.

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